# SECTION 5: TECHNOLOGY ASSESSMENT

This technology assessment of available data sources is intended to determine the depth and breadth of effectiveness data for various erosion and sediment controls, and to identify the amount and quality of data available to describe the performance of all currently used and innovative construction site runoff control practices, the ability of each practice to effectively control impacts due to runoff, and the design criteria or standards currently used to size each practice to ensure effective control of runoff.

## 5.1 CONSTRUCTION EROSION AND SEDIMENT CONTROLS

### 5.1.1 INTRODUCTION

This assessment addresses the erosion and sediment control BMPs for the construction phase of development. Prior to initiating this aspect of the work, EPA reviewed the findings of information sources and literature assessments to identify the appropriate definition of "performance" or the various definitions or "levels" of performance that are considered in evaluating and defining the levels of performance for these BMPs. A scientific-based approach to describe the performance of erosion and sediment control BMPs was devised similar to the approach developed by Barfield and Clar (1985) in the evaluation of the Maryland Erosion and Sediment Control Standards, as well as the one recently developed in the American Society of Civil Engineers BMP Database (ASCE, 1999). The approach used in this assessment has been designed to provide the information needed to address several important issues, including whether to use a design-based approach, or an effluent-based concentration, or a loading approach in reporting on the current status of the technology. This sub-section identifies the following:

- The amount and quantity of data available to describe the performance of all currently used and innovative runoff control practices.
- The ability of each practice to effectively control impacts due to runoff.
- The design criteria or standards currently used to size each practice to ensure effective control of runoff.

Before a detailed evaluation of the BMPs can be provided, some background information is necessary. Sub-section 5.2 describes the procedure for assessing the technology. Sub-section 5.3 provides a historical background on the subject. Next, sub-section 5.4 presents a discussion of goals, control strategies, criteria, and standards in general, and sub-section 5.5 provides a detailed description and discussion of each BMP.

In the discussion of BMPs in sub-section 5.5, the major focus will be on sediment. This does not imply that there are no other impacts; however, construction BMPs have focused on erosion and sediment control rather than on other impacts.

In the assessment of BMPs, considerable attention is focused on whether to use a design-based approach, an effluent-based concentration, or a loading approach in reporting on the current status of the technology. Attention is also given to the recent emphasis in the literature on the use of an integrated approach to evaluate impacts to the receiving waters and downstream areas.

### 5.1.2 PROCEDURE FOR TECHNOLOGY ASSESSMENT

#### 5.1.2.1 Identification of Performance Goals

In assessing the literature, particular consideration was given to definitions of performance of BMPs and how they addressed the range of receiving water impacts identified. It is important to point out that the overarching performance goal of all the BMPs is to minimize the impact of construction site runoff on receiving waters and downstream areas.

Control strategies that have been identified for construction BMPs can be divided into three categories.

**Strategy 1.** Control Based on Design Standards—Control at this level is based on standard designs that may include such things as volume requirements for reservoirs, detention time, and trapping efficiency that do not directly limit an allowable discharge to receiving waters or limit a downstream impact.

**Strategy 2.** Control Based on Effluent Standards—Control at this level is based on limiting the quantity of one or more substances such as peak discharge, runoff volume, TSS, and settleable solids. This directly addresses effluent but does not directly address downstream impacts.

**Strategy 3.** Control Based on an Integrated Approach—Control at this level uses an integrated approach (Snodgrass et al., 1998), including biological, chemical, and physical criteria, to define BMP performance. A combination of water quality, biohabitat, and geomorphic criteria is used to evaluate whether a receiving stream meets the targeted goal of fishable and swimmable, or the extent of departure from this goal.

The majority of BMPs address Strategies 1 or 2. Although Strategy 3 is being discussed in the literature, it has not been adopted in practice. There is an analog in the surface mining industry, where a cumulative hydrologic impact analysis on a watershed basis is required by the U.S. Surface Mining and Reclamation Act of 1977 (PL95-87). When moving from Strategy 2 to Strategy 3, a number of other parameters are added to the performance criteria in Strategy 2, including (1) stream buffer retention and thermal impacts considerations, (2) volume control considerations such as these presented in the Low Impact Development concept approach, which are added to the peak discharge and ground water recharge criteria to achieve maintenance of hydrologic function at a site-specific level, and (3) geomorphic criteria as described by Lane (1955), Leopold et al. (1964), Rosgen (1996), and others.

An important point must be made about controlling sediment. From a practical standpoint, a reasonably sized structure should not necessarily be expected to meet an effluent TSS standard unless the TSS specified in the standard is set at a very high value or unless some form of chemical treatment is used to enhance flocculation. The settling velocity for primary clay particles is in the range of feet per month for all but the largest particles. Since these size particles are frequently encountered in large percentages in sediment from construction sites, the expected trapping efficiencies will not approach 100 percent, nor will the effluent TSS be in the range of 100 mg/L or lower (Haan et al., 1994).

### 5.1.2.2 Goals, Environmental Impact Areas, And Assessment Scales

For the purposes of this report, impact areas are divided into three categories: local area, receiving water, and downstream areas.

**Local Area.** This is the area between the construction site and the receiving stream. Typically, these areas have ephemeral streams with low baseflows and highly variable flow rates. In these areas, flows fluctuate widely, with geomorphology and habitat being very susceptible to changes in hydrologic regime (Klaine, 2000). In some developments, there would essentially be no local area, and flows would exit directly into receiving waters.

**Receiving Waters.** This is the point at which flows enter a well-defined stream. Depending on the local geology, flows may primarily be ephemeral, there may be a well-established baseflow, or there may be intermediate flow. The degree to which flows, sediment, and chemicals impact receiving waters depends largely on the type of receiving water. For example, if the receiving waters have a low baseflow and highly variable flow rates, the habitat and geomorphology will be very sensitive to significant changes in the hydrologic regime. However, if the receiving waters have a high baseflow, the sensitivity to changes in flow rate will be much less and the primary problems will likely be chemical in nature. Thus, it is important to address impacts on a site-specific basis.

**Downstream Areas.** A definition of the downstream area can be somewhat nebulous. (A definition of the aerial extent of "downstream areas" is something that needs to be developed in follow-up studies.) However, consideration of this area is important. For example, use of peak discharge criteria may directly control the local area impacts and impacts to the point at which flow enters the receiving waters. If the watershed being considered is combined with other downstream watersheds and all use peak discharge control without controlling runoff volume, there can be an increase in flooding due to superposition of long duration peak flows exiting the numerous reservoirs (Smiley and Haan, 1976). This increased discharge can negatively impact channel geomorphology, habitat, and riparian areas.

Another important issue related to construction is the fraction of the watershed under construction at any one time. One argument about the relative importance of the construction phase versus the post-construction phase is that the construction phase is short-lived and the impact may be reversible after the site has stabilized. While this argument may have some validity on the local area, it is invalid when considering the downstream areas. On a larger watershed under development, major construction may occur in the watershed for a long time, with a potential long-term major cumulative impact. When considering the entire watershed, it may be desirable to limit the area under construction at any one time to prevent exceeding some threshold that would result in an irreversible impact. This indicates the need to conduct a cumulative impact analysis on a river basin scale to evaluate the potential for such an impact to occur.

When considering area impacts, the following comments can be made about the strategies listed above.

**Strategy 1.** No guarantees can be made that impacts would be controlled at any level unless the design standards are highly conservative. This would result in overdesign for most situations so that the standard would be adequate for all situations.

**Strategy 2.** This strategy should ensure control at the local level. Downstream, the impacts may be positive or negative as a result of the control. Examples include the control of peak discharge only in storm water runoff. Control of peak discharge on all construction areas at the local level can result in increased peak discharge downstream (Smiley and Haan, 1976). These increases result from detaining increased volumes of runoff resulting from urbanization and releasing them at the predisturbed peak rate over a long period of time.

**Strategy 3.** This approach should ensure control in both the local area and downstream areas.

Scale is very important to BMP effectiveness analyses. A given BMP may be quite effective in controlling impacts nearby but have a significant negative impact when applied over a large area. In the final analysis, effectiveness should be evaluated at multiple scales before a decision is made. This will require both local- and watershed-level analyses.

#### 5.1.2.3 Qualitative Versus Quantitative Assessment

In the assessments, impacts may be addressed on a qualitative or a quantitative basis. The difference can be explained in the following manner, using water temperature as an example. It is well known that turbidity impacts the depth of penetration of solar energy into a waterbody; hence, turbidity impacts temperature. When evaluating the impact of standards on water temperature, it is obvious that a TSS standard directly addresses water temperature because of the impact of TSS on turbidity. Thus, a qualitative analysis would simply state that TSS standards may impact water temperature, but give no degree to which the standard does impact temperature. A quantitative analysis, however, would define the degree to which a given TSS standard increased or decreased the impact of TSS on temperature.

### 5.1.3 REVIEW OF HISTORICAL APPROACHES TO EROSION AND SEDIMENT CONTROL

Most early sediment control was related to agriculture and was installed as a way to maintain our natural resource base. On-site control was the primary emphasis, attempting to prevent erosion rather than trap sediment. Strategies were developed to minimize exposure of bare soil to the erosive power of rainfall and runoff, using aboveground cover management, residue management, strip cropping, and terracing to limit the length of overland flow. Impacts to receiving streams and downstream areas had not yet been identified as an issue. In the 1960s, concern began to be expressed about the quantities of sediment in streams and reservoirs, and sediment was first identified as a pollutant. Initially, the major focus of sediment control was on the surface mining industry, with the passage of the Clean Water Act and then the Surface Mining, Reclamation, and Control Act (SMRCA) (PL 95-87). The first approach taken to sediment control was a design standard, requiring a sediment detention basin with a 24-hour detention time; TSS standards of 35 mg/L average and 70 mg/L peak were also promulgated, but were not typically enforced. The U.S. Environmental Protection Agency (USEPA) later evaluated the TSS standard and moved to a settleable solids standard of 0.5 mL/L, based on a modeling effort that showed that it was not possible to trap fine sediments, but that a 0.5 mL/L settleable solids standard could be met with a reasonably sized sediment basin (Ettinger and Lichty, 1979).

In the late 1960s and early 1970s, sediment in streams and waterways originating from urban construction sites became an issue, which was then addressed in the Clean Water Act. EPA developed a list of BMPs and standards for their construction (USEPA, 1971). In general, these standards were adopted from those of other agencies and were not based on studies related to urban runoff.

In 1987, the Clean Water Act was amended to include storm water discharges from urban areas. The Phase I NPDES Storm Water regulations were published in 1990, requiring all municipalities with Municipal Separate Storm Sewer Systems (MS4) serving populations greater than 100,000, construction sites 5 acres and larger, and certain industrial sites to obtain a permit. The permit required the development of a storm water pollution prevention plan (SWPPP) that typically included a storm water and sediment control plan. In 1999, the Phase II NPDES storm water regulations were published, extending permit coverage to construction sites of 1 acre or larger and municipalities with populations greater than 50,000 (or populations greater than 10,000 where population density is more than 1,000 people per square mile). The regulations allow use of general permits in lieu of individual site or facility permits. The degree of oversight of construction varies widely among the states.

In the last two decades, increased concern at the local level has been focused on sediment pollution of streams and waterways, particularly originating from construction, while less concern has been focused on the impacts of increased construction on storm water and chemical production. Much of this government concern originated from the Phase I and Phase II NPDES storm water regulations. A number of states and their local agencies have developed standards and BMPs for sediment control, most of which do not have a scientific basis, but were adopted from other agencies. Some states, however, did conduct studies that gave their standards some scientific basis. For example, Maryland evaluated its BMP standards in the 1980s by using modeling techniques, and the state changed its sediment basin standards to account for the impacts of surface area on the trapping efficiency in sediment ponds. Based on typical soils in the region and modeling studies, the state adopted a surface area to peak discharge ratio of 0.01 cubic feet per second (cfs) per acre as a criterion (Barfield and Clar, 1985; McBurnie et al., 1990). Maryland was thus the first state to use a design criterion that was related to the overflow rate. Other states also used some of Maryland's results (Smolen et al., 1988).

Recent efforts have moved closer to an effluent standard approach. South Carolina conducted a detailed analysis and published regulations that required a trapping efficiency or settleable solids standard (SCDHEC, 1995). In addition, results from a detailed model were used to develop simplified design aids (Hayes and Barfield, 1995; Holbrook et al., 1998). Some municipalities are following suit to develop scientifically based standards of their own. For example, in 1998 Louisville, Kentucky, (Hayes et al., 2001) developed standards and design aids for storm water and sediment control, following the example of South Carolina.

There are no analogous examples in which the integrated approach to storm water and sediment control have been used on construction sites. The closest analog is the Cumulative Hydrologic Impact Analysis (CHIA) required in surface mining by the SMRCA. SMRCA requires each applicant for a surface mining permit to conduct a hydrologic impact analysis. Subsequently, the regulatory authority is required to conduct a CHIA for the entire watershed. It should be pointed out that although a CHIA is required, it is seldom undertaken on a scale that is useful.

Many of the advances in sediment control have been based on the capability to predict, *a priori*, the ability of a given design to meet a standard. For example, when the settleable solids standard was developed for surface mining, most regulatory authorities adopted it with the requirement that permit applicants would demonstrate through the use of widely accepted computer models that the proposed design would meet the settleable solids standard.

Most of the early work in modeling sediment production stemmed from efforts in the 1950s to develop a soil loss equation that would apply to the entire nation and allow evaluation of alternative erosion control practices. This led to the relationship known as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965) and its subsequent derivative, the Revised USLE (RUSLE) (Renard et al., 1994). These efforts focus on erosion control; thus, the relationships do not predict sediment yield. A flurry of efforts in the late 1970s and early 1980s lead to the development of sediment yield relationships such as the Modified USLE (MUSLE) (Williams, No Date), the CREAMS model (Knisel, 1980), SEDCAD (Warner, 1998), and SEDIMOT II (Wilson et al., 1982) and its derivatives. The MUSLE and CREAMS models did not include methods to evaluate the impact of sediment trapping structures, but SEDIMOT II contained relationships developed at the University of Kentucky to predict the impact of reservoirs (Ward et al., 1977; Wilson and Barfield, 1984), check dams (Hirschi, 1981), and vegetative filter strips (Hayes et al., 1984). The MUSLE and , SEDCAD and SEDIMOT II models were based on single storms, while the CREAMS model was based on continuous simulation modeling. Details on these models can be found in Haan et al. (1994).

More recently, modeling has improved, resulting in several new relationships. The WEPP watershed model is one example of a continuous simulation approach. It includes computational procedures for a wide variety of sediment control structures (Lindley et al., 1998). Another example of a single storm-based model is SEDIMOT III (Barfield et al., 1996), which modifies the earlier SEDIMOT II model to include channel erosion routines and a wide variety of sediment control techniques. A significant drawback in the SEDIMOT III and WEPP models is that they do not have a good technique for predicting the impact of filter fence, which is the most common technique used today for sediment control. The authors of SEDCAD have attempted to provide algorithms to represent (silt) filter fence removals, although work remains prior to global acceptance in the literature.

Concerns for changes in geomorphology resulting from flow alterations have resulted in several modeling approaches. Early efforts were focused on what is known as the regime theory, in which changes in channel property are linked, qualitatively, to changes in flow. Examples include models of Lane (1955) and Schumm (1977). In addition, some statistically based models were developed, but they are not universally applicable (Blench, 1970; Simons and Albertson, 1960). More recently, models have been developed using physically based concepts to predict changes in geomorphology as related to changes in flow. The models of Chang (1988) are good examples. It is possible to predict, to a limited extent, the change in channel properties as impacted by changes in flow.

The impact of changes in flow and geomorphology on habitat is one major area where information is lacking. Although this deficiency can be addressed in a qualitative manner, it is not possible to predict quantitatively how a given change in geomorphology will impact habitat. Additional information is needed to develop a strategy based on the integrated assessment approach.

### 5.1.4 GOALS, CONTROL STRATEGIES, CRITERIA, AND STANDARDS

#### 5.1.4.1 Goals, Control Strategies, Criteria, And Standards: How They Relate

The relationship between goals, control strategies, criteria, and standards can sometimes be confusing. For the purpose of the discussion of construction BMPs, the following definitions will be used.

**Goal.** The overarching objective of having a storm water, sediment, and pollution control program is known as the goal. It is what the program is trying to achieve. All BMPs should relate to that goal. As stated earlier, the goal of this program is to minimize the impact of construction on receiving water and downstream areas. The impacts of concern are identified in the Environmental Assessment.

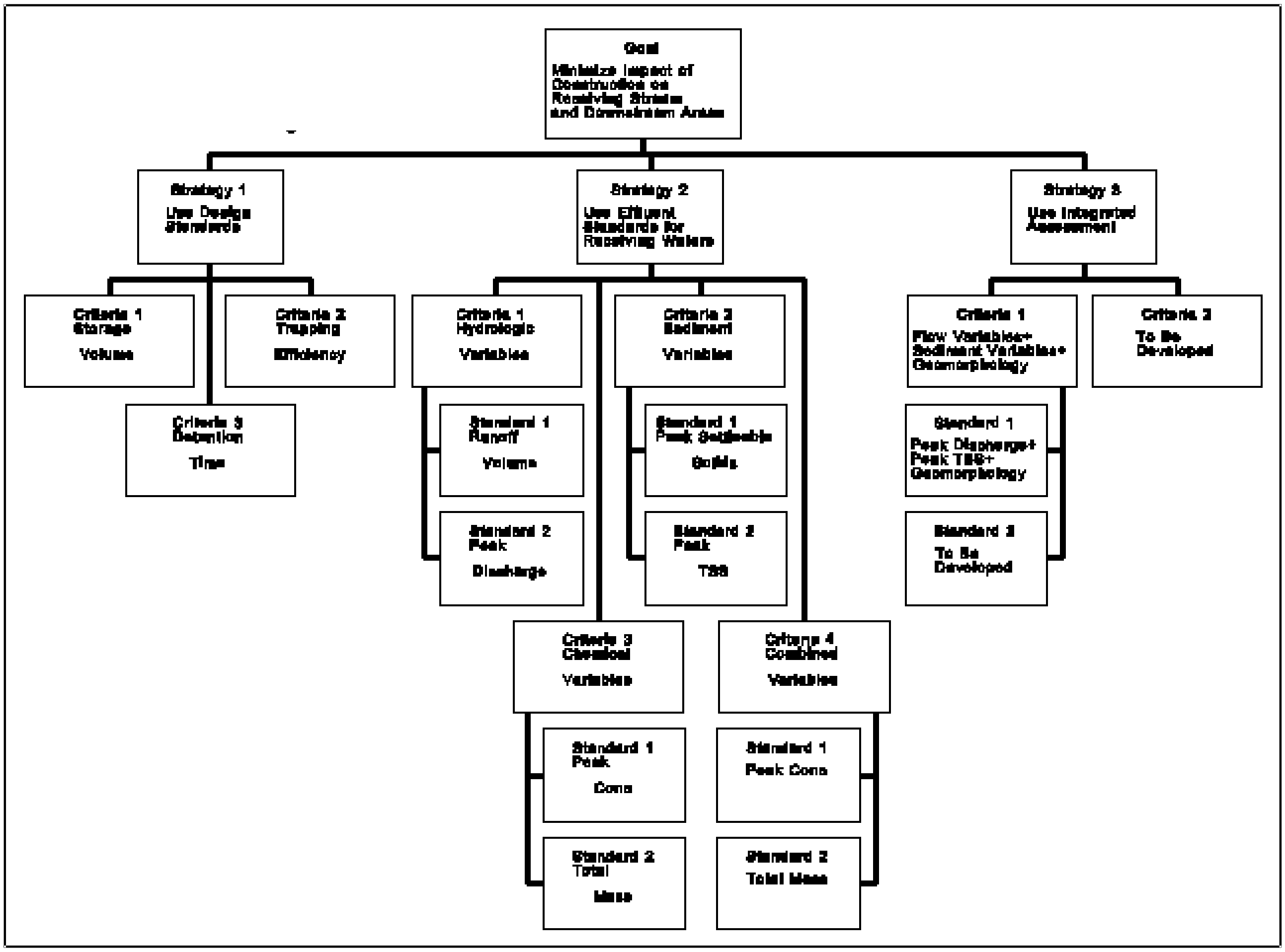
**Control Strategies.** The methods by which the regulatory agency tries to achieve the goal are called control strategies.

**Criteria.** The particular variables that are targeted by a given strategy are known as the criteria. For example, if the strategy is to control impacts by limiting the discharge of sediment to the receiving waters, then sediment becomes the criterion.

**Standard.** The specific variable chosen for the criteria and its numeric value is referred to as the standard. For example, if the control strategy is to limit sediment discharge to the receiving waters, the criterion is sediment, and the particular limiting variable and numeric value chosen is a peak settleable solids concentration of 0.5 mg/L, then the standard would be a peak settleable solids concentration of 0.5 mg/L.

The relationship among goals, control strategies, criteria, and standards is shown graphically in Figure 5-1.

**Figure 5-1. Flow Diagram Showing Relationship Among Goals, Strategies, Criteria and Standards**



### 5.1.4.2 Levels of Performance or "How Well Do The Strategies Work?"

Table 5-1 provides a description on the level of performance for the three strategies discussed in sub-section 5.2.1.

**Table 5-1. Description of Levels of Performance of Three Control Strategies**

| Level | Description of Performance |
|---|---|
| 0 | No consideration of impact. |
| 1 | Performance defined by a design standard. No guarantee that the design will control the impact to a desired level on the specific watershed. Example: reservoir volume standard for runoff control. |
| 2 | Effluent standard based on controlling a single entity entering receiving waters. Control of the single parameter will not guarantee that the desired protection will occur for receiving waters or downstream impact. Example: controlling peak storm water discharge or peak TSS. |
| 3 | Effluent standard based on controlling two or more entities entering receiving waters, but not all entities causing environmental impact. Example: controlling peak discharge and sediment, but not storage volume or runoff volume. |
| 4 | Effluent standards for all entities entering receiving waters and causing environmental impact. Even controlling all quantities entering receiving waters will not guarantee that there are no undesired downstream impacts. Example: Controlling runoff rate, runoff volume, peak discharge, and TSS in receiving streams does not guarantee that there will be no undesirable biological impacts. |
| 5 | Control based on integrated evaluation of impacts on receiving stream and downstream. |

### 5.1.4.3 Strategies, Criteria, Standards, And Enforcement

The effectiveness of a given strategy, criterion, or standard is directly related to the ability of an enforcement agency to enforce the rules. Thus, a given standard may theoretically provide excellent protection to the environment, but be so difficult to enforce that it is less effective than a less stringent standard that is enforceable. In general, the difficulty in enforcement increases as the level of desired performance increases. An estimate of relative difficulty in enforcement is given in Table 5-2 for the various levels of performance from Table 5-1. For example, it is easier to enforce the design standard, since enforcement is based entirely on reviewing plans and inspection of the site to ensure that the plans are put into action properly.

Important issues related to enforcement include the following:

- *A priori* demonstration by the best computational technology that the proposed design can meet the standard.
- As-built inspections to verify that the installed practices match the approved plan.
- Self-monitoring of effluent in the case of effluent standards, with spot checks by the regulatory authority to make sure that evaluations are being done properly.
- Evaluation of downstream impacts.
- Clearly defined rules for monitoring the effectiveness of a practice.

**Table 5-2. Descriptions of Levels of Difficulty in Enforcement**

| Level of Performance from Table 5-1 | Difficulty in Enforcing (Relative) | Description of Difficulty |
|---|---|---|
| 0 | 0 | Nothing to enforce. |
| 1 | 1 | Enforcement consists of reviewing plans and ensuring proper installation and maintenance. |
| 2 | 2 | Enforcement requires some monitoring and typically requires a preconstruction review of plans and submission of calculations showing that the standard can be met. |
| 3 | 2.5 | Same as above except multiple variables. |
| 4 | 2.5 | Same as above. |
| 5 | 5 | Enforcement requires some *a priori* demonstration of the expected flow and concentration changes and their impact on receiving waters and downstream variables. In addition, routine monitoring of downstream variables such as geomorphology, aquatic life, aesthetics, and riparian zones would be required. |

***A Priori* Demonstration of Performance.** *A priori* demonstration that a given design can meet the standard is very important. Experience with the surface mining industry indicates that a sediment control plan is no better than its design. In other words, if the best computational technology indicates that the design will not meet the standard, then field monitoring of the BMP is not likely to show that the standards are being achieved. Thus, it will be important to have scientifically based and verified computational technologies to predict the performance of BMPs relative to meeting a specified standard.

In recognition of this need EPA funded the development of the National Stormwater BMP Database project by the Urban Water Resources Research Council of the American Society of Civil Engineers (ASCE, 1999) to establish the state of the art of BMP performance with respect to pollutant removal and peak discharge control (Level of performance 3, see Table 5-1). The database can be found at: http://www.bmpdatabase.org/. The ASCE project team prepared a report that contains several different methods for evaluating BMP efficiency data. This report presents statistically based approaches that involve conducting a statistical analysis to characterize inflow and outflow event mean concentrations (EMCs), and then evaluates whether or not there is a statistically significant difference between the two. The application of this approach in evaluating the data contained in the database has led the study team to conclude that evaluating effluent quality is a good indicator of performance of BMPs with respect to pollutant removal. Although the database currently is designed to address only permanent stormwater management practices, the methodologies could easily be adapted to the evaluation of erosion and sediment controls.

**As-built Inspections.** Another important issue related to enforcement is as-built inspections of installed practices. Although the rules may call for certification by an appropriately licensed professional, it is important that the regulatory authority conduct routine inspections to ensure that the licensed professionals are doing their job properly.

**Monitoring.** Finally, there are issues related to self-monitoring versus monitoring conducted by the regulatory authority. The use of effluent standards would require some type of monitoring to ensure that performance meets the standards. However, storm water and sediment control structures that control flows are highly variable and temporally stochastic. This means that it is not possible to plan ahead when the monitoring will occur. It will be necessary to have trained professionals to conduct the monitoring.

A monitoring methodology for BMPs should meet three criteria: (1) provide scientifically based numbers to evaluate effectiveness, (2) be executable and sufficiently simple to allow the use of trained technicians who would reasonably be available to do the monitoring, and (3) be adequate to ensure that the desired standards are met without excessive sampling or analysis. The first criterion could be met by providing clear documentation on the monitoring methodology that specifies times, frequency, and location of sampling relative to storms, as well as clearly articulated protocols for handling samples. The second criteria can be met by being sure that the techniques proposed have actually been field-applied by technicians in the monitoring business. The third criterion can be evaluated by an error analysis that determines the expected accuracy of measurement as a function of number and frequency of sampling.

Several possible criteria or standards have special measurement problems that should be mentioned. These include criteria or standards based on trapping efficiency, and/or effluent TSS and settleable solids (average or peak). The issues associated with these criteria are discussed below.

**Trapping Efficiency.** Literature citations frequently include studies that attempt to measure trapping efficiency by sampling one or more inflow and outflow concentrations (Barrett et al., 1995). While this simplicity seems attractive, it is a grossly erroneous measure of trapping efficiency. A correct definition of trapping efficiency is given in Equation 1:

Equation 1: $$TE = (M_i - M_o) / M_i$$

where: $M_i$ is inflow total mass
$M_o$ is outflow total mass
$M_i$ is given by integrating the product of inflow concentration and inflow rate over the duration of a hydrograph

or

Equation 2: $$M_i = \int_0^{t_D} C_i \, q_i \, dt$$

where: $C_i$ is inflow concentration
$q_i$ is inflow flow rate
t is time
$t_D$ is the duration of the storm

Outflow total mass $M_o$ is calculated by substituting the subscript o for i in Equation 2. Thus, to monitor trapping efficiency correctly, it is necessary to measure both flow and concentration as a function of time over the duration of both inflow and outflow. Such measurement is quite difficult and time-consuming, requiring many samples.

**Statistical Evaluation of Inflow/Outflow Data (mean, median, standard deviation, coefficient of variance).** To measure average or peak TSS, it is necessary to measure TSS in the effluent over the duration of the outflow hydrograph as well as the flow rate. This requires that multiple samples be taken and that the samples be centered around the peak discharge. The ACSE database data analysis document has the ability, depending upon the number of samples collected, to show a difference between various samples. Again, this is time-consuming and difficult since the timing of an event and the timing of the peak discharge are not known *a priori*. The average concentration is a weighted concentration, using flow rate as a weighting function.

## 5.1.5 CONTROL TECHNIQUES, BMP SYSTEMS

### 5.1.5.1 Erosion Control and Prevention

#### 5.1.5.1.1 Planning, Staging, Scheduling

**General Description**

A construction sequence schedule is a specified work schedule that coordinates the timing of land-disturbing activities and the installation of erosion and sediment control measures. The goal of a construction sequence schedule is to reduce on-site erosion and off-site sedimentation by performing land-disturbing activities and installing erosion and sediment control practices in accordance with a planned schedule (Smolen et al., 1988).

Construction site phasing involves disturbing only part of a site at a time to prevent erosion from dormant parts (Claytor, 1997). Grading activities and construction are completed and soils are effectively stabilized on one part of the site before grading and construction commence at another part. This differs from the more traditional practice of construction site sequencing, in which construction occurs at only one part of the site at the time, but site grading and other site-disturbing activities typically occur simultaneously, leaving portions of the disturbed site vulnerable to erosion. Construction site phasing must be incorporated into the overall site plan early on. Elements to consider when phasing construction activities include the following (Claytor, 1997):

- Managing runoff separately in each phase.
- Determining whether water and sewer connections and extensions can be accommodated.
- Determining the fate of already completed downhill phases.
- Providing separate construction and residential accesses to prevent conflicts between residents living in completed stages of the site and construction equipment working on later stages (USEPA, 2000).

**Applicability**

Construction sequencing can be used to plan earthwork and erosion and sediment control activities at sites where land disturbances might affect water quality in a receiving waterbody.

**Design and Installation Criteria**

Construction sequencing schedules should, at a minimum, include the following (NCDNR, 1988; MDE, 1994):

- The erosion and sediment control practices that are to be installed

- The principal development activities
- The measures that should be installed before other activities are started
- The compatibility with the general contract construction schedule

Table 5-3 summarizes other important scheduling considerations in addition to those listed above.

**Table 5-3. Scheduling Considerations for Construction Activities**

| Construction Activity | Schedule Consideration |
|---|---|
| Construction survey stakeout | Prior to initiating any construction activity a construction survey stakeout should be conducted. The stakeout should identify the limits of disturbance and location of control structures, especially perimeter controls. |
| Pre-construction meeting between owner, contractor, and regulatory agency | This meeting should take place before any construction activity begins at the site. The survey stakeout is reviewed, especially the limits of disturbance and location of controls. |
| Construction access—entrance to site, construction routes, areas designated for equipment parking | This is the first land-disturbing activity. As soon as construction takes place, any bare areas should be stabilized with gravel and temporary vegetation. |
| Clearing and grading required for the installation of controls | In conjunction with the construction access, the clearing and grading required for the installation of E&S controls should take place. |
| Sediment traps and barriers—basin traps, silt fences, outlet protection | After the construction site has been accessed, principal basins should be installed, with the addition of more traps and barriers as needed during grading. |
| Runoff control—diversions, perimeter dikes, water bars, outlet protection | Install key practices after the installation of principal sediment traps and before land grading. Additional runoff control measures may be installed during grading. |
| Runoff conveyance system—stabilize streambanks, storm drains, channels, inlet and outlet protection, slope drains | If necessary, stabilize streambanks as soon as possible, and install the principal runoff conveyance system with runoff control measures. The remainder of the systems may be installed after grading. |
| Land clearing and grading—site preparation (cutting, filling, and grading; sediment traps; barriers; diversions; drains; surface roughening) | Implement major clearing and grading after installation of principal sediment and key runoff control measures, and install additional control measures as grading continues. Clear borrow and disposal areas as needed, and mark trees and buffer areas for preservation. |
| Surface stabilization—temporary and permanent seeding, mulching, sodding, riprap | Immediately apply temporary or permanent stabilizing measures to any disturbed areas where work has been either completed or delayed. |
| Building construction—buildings, utilities, paving | During construction, install any erosion and sediment control measures that are needed. |
| Landscaping and final stabilization—adding topsoil, trees, and shrubs; permanent seeding; mulching; sodding; riprap | This is the last construction phase. Stabilize all open areas, including borrow and spoil areas, and remove and stabilize all temporary control measures. |

**Effectiveness**

Construction sequencing can be an effective tool for erosion and sediment control because it ensures that management practices are installed where necessary and when appropriate. A comparison of sediment loss from a typical development and from a comparable phased project showed a 42 percent reduction in sediment export in the phased project (Claytor, 1997).

**Limitations**

Weather and other unpredictable variables may affect construction sequence schedules. The proposed schedule and a protocol for making changes resulting from unforseen problems should be plainly stated in an applicable erosion and sediment control plan.

**Maintenance**

The construction sequence should be followed throughout the project, and the written erosion and sediment control plan should be modified before any changes in construction activities are executed. The plan can be updated if a site inspection indicates the need for additional erosion and sediment control as determined by contractors, engineers, or developers.

**Cost**

Construction sequencing is a low-cost BMP because it requires a limited amount of a contractor's time to provide a written plan for the coordination of construction activities and management practices. Additional time might be needed to update the sequencing plan if the current plan is not providing sufficient erosion and sediment control.

Although little research has been done to assess the costs of phasing versus conventional construction costs, it is known that it will be to implement successful phasing for a larger project (Claytor, 1997).

### 5.1.5.1.2 Vegetative Stabilization

Vegetation can be used during construction to stabilize and protect soil exposed to the erosive forces of water, as well as post-construction to provide a filtration mechanism for storm water pollutants. The following discussion refers to vegetative stabilization as a construction BMP that stabilizes and protects soil from erosion.

**General Description**

Vegetative stabilization measures employ plant material to protect soil exposed to the erosive forces of water and wind. Selected vegetation can reduce erosion by more than 90 percent (Fifield, 1999). Natural plant communities that are adapted to the site provide a self-maintaining cover that is less expensive than structural alternatives. Plants provide erosion protection to vulnerable surfaces by the following (Heyer, No Date):

- Protecting soil surface from the impact of raindrops.
- Holding soil particles in place.
- Maintaining the soil's capacity to absorb water.
- Using living root systems to hold soil in place, increasing overall bank stability.
- Directing flow velocity away from the streambank.
- Acting as a buffer against abrasive transported materials.
- Causing sediment deposition, which reduces sediment load and reestablishes the streambank.

The designer should be aware of and respond to local conditions that may influence the development of vegetative stabilization measures. As with any planting design, climate, maintenance practices, the availability of plant material (including native species), and many other factors will influence such considerations as plant or seed mix selection, installation methods, and project scheduling.

**Slope Stabilization.** On slopes, the goal of vegetative stabilization is not only to reduce surface erosion but also to prevent slope failure. Vegetation should provide dense coverage to protect soils from the direct impact of precipitation and help intercept runoff. A variety of plants should be used to provide root systems that are distributed throughout all levels of the soil, increasing slope shear strength and giving plants a greater ability to remove soil moisture. Uniform mats of shallow rooting plants should be avoided because, while such plants may increase runoff infiltration, they cannot remove soil moisture beyond the surface level, leaving slopes potentially saturated and prone to slippage. Shallow, interlocking root systems may also increase the size of a soil slippage by holding together and pulling down a larger area of slope after a small section has given way. Large trees that have become unstable may also pull down slopes and should be removed. Using plants with low water requirements can reduce the potential for soil saturation from irrigation.

**Swale Stabilization.** On swales, the goal of vegetative stabilization is to prevent erosion within the swale, where runoff is concentrated and flows at higher velocities. If natural stream channels are involved, vegetation with deep root systems should be preserved, or if absent, planted above the channel to help maintain the channel banks. More information is provided in the subsequent section dealing with grass-lined swales.

**Surface Stabilization.** On large, flat areas, the goal of vegetative stabilization is to reduce the loss of surface soil from sheet erosion. Vegetation should provide complete coverage to reduce the force of precipitation, which can shift soil particles to seal openings in the soil, reducing infiltration and increasing runoff. Vegetation should also provide many stem penetrations to slow runoff and increase infiltration. Deep rooting plants are less critical for erosion control in flat areas than on slopes because soils are not subject to the same forces that may cause slippage on a slope. However, trees and shrubs can increase infiltration, lessening the buildup of runoff, and transpire large volumes of water, reducing soil saturation.

In areas susceptible to wind erosion, the goal of vegetative stabilization is to establish direct protection of the soil. Vegetation should provide dense and continuous surface cover. Binding the soil deeply is generally not a requirement. The ideal vegetation for this purpose is grass, which forms a mat of protection. In areas where the vegetation is developed, the grass generally has high maintenance requirements. In less developed, open areas, unmown grass, including perennial native species, can be used to provide protection. Trees and shrubs also can provide protection from the wind.

**Shoreline Stabilization.** In lakes and ponds, the goal of vegetative stabilization is to prevent erosion of the shoreline. Wetland plants anchor the bottom of the lake or pond adjacent to the shore and help dissipate the erosive energy of waves. An important consideration in planting along shorelines is the need to establish favorable conditions for plant establishment and growth. These include the proper grading of side slopes and the control of upland erosion to prevent the buildup of silt and associated pollutants in the water. Designers should maintain awareness of regulatory requirements that may influence vegetation projects in a wetland environment (USAF, 1998).

Vegetation used for shoreline stabilization work should be native material selected on the basis of strength, resiliency, vigor, and ability to withstand periodic inundation. Woody vegetation with short, dense, flexible tops and large root systems works well. Other important factors include rapid initial growth, ability to reproduce, and resistance to disease and insects.

According to Heyer (No Date), most streambank stabilization plantings have used various willows, including black willow (*Salix nigra*), sandbar willow (*S. interior*), meadow willow (*S. petiolaris*), heartleaf willow (*S. rigida*), and Ward willow (*S. caroliniana*). The size used depends on the severity of the erosion and the type of bank to be stabilized. Whatever the size, it is important to use dormant cuttings and to remove all lateral branches. Most tree revetment projects used either eastern red cedar (*Juniperus virginiana*) or hardwoods such as northern pin oak (*Quercus ellipsoidalis*). Important suggestions include the following:

- Choose trees with many limbs and branches to trap as much sediment as possible.
- Select decay-resistant trees.
- Use recently cut trees—dead trees are more brittle and likely to break apart.
- The tree size-diameter of the tree crown should be about two-thirds of the height of the eroding bank.

- Cut off any trunk without limbs.

- Place the tree revetments overlapping, butt end pointing upstream.

- Begin and end revetments at stable points along the bank.

- Choose an anchoring system according to the bank material to be stabilized and the weight of the object to be anchored.

Vegetative measures for streambank stabilization offer an alternative to structural measures and are becoming well known as bioengineering techniques for streambanks. Utilizing vegetative material for streambank stabilization could be the first step in the reestablishment of the riparian forest, which is essential for long-term stability of the streamside and floodplain areas. Each site must be evaluated separately as to the feasibility of using natural material (Heyer, No Date).

Vegetative streambank stabilization, with the goal to protect streambanks from the erosive forces of flowing water, is generally applicable where bankfull flow velocity does not exceed 6 ft/sec and soils are erosion resistant (Smolen, 1988). Table 5-4 includes general guidelines for maximum allowable velocities in streams to be protected by vegetation.

**Table 5-4. Conditions Where Vegetative Streambank Stabilization Is Acceptable**

| Frequency of Bankfull Flow | Maximum Allowable Velocity for Highly Erodible Soil | Maximum Allowable Velocity for Erosion-Resistant Soil |
|---|---|---|
| > 4 times/yr | 4 ft/sec | 5 ft/sec |
| 1 to 4 times/yr | 5 ft/sec | 6 ft/sec |
| < 1 time/yr | 6 ft/sec | 6 ft/sec |

Source: Smolen, 1988.

**Temporary Vegetative Stabilization.** Temporary vegetative cover such as rapidly growing annuals and legumes can be used to establish a temporary vegetative cover. Such covers are recommended for areas that (Fifield, 1999):

- Will not be brought to final grade within 30 days or are likely to be redisturbed.

- Require seeding of cut and fill slopes under construction.

- Require stabilization of soil storage areas and stockpiles.

- Require stabilization of temporary dikes, dams, and sediment containment systems.

- Require development of cover or nursery crops to assist with establishing perennial grasses.

Examples of temporary vegetation include wheat, oats, barley, millet, and sudan grass. Temporary seeding may not be effective in arid or semi-arid regions where seasonal lack of moisture prevents germination. It may be necessary to use a mixture of warm and cool season grasses to ensure germination. Mulching and geotextiles can be used to help provide temporary stabilization with vegetation, particularly in situations where establishing cover may be difficult.

**Permanent Vegetative Stabilization.** Permanent vegetative cover such as a perennial grass or a legume cover can be used to establish a permanent vegetative cover. Permanent vegetation is recommended for (Fifield, 1999):

- Final graded or cleared areas where permanent vegetative cover is needed to stabilize the soil
- Slopes designated to be treated with erosion control blankets
- Grass-lined channels or waterways designed to be protected with channel liners

The following sub-sections discuss the various types or means of providing vegetative stabilization.

#### 5.1.5.1.2.1 Grass-lined Channels

**General Description**

Grass-lined channels, or swales, convey storm water runoff through a stable conduit. Vegetation lining the channel reduces the flow velocity of concentrated runoff. Grassed channels are usually not designed to control peak runoff loads by themselves and are often used in combination with other BMPs such as subsurface drains and riprap stabilization.

**Applicability**

Grassed channels should be used in areas where erosion-resistant conveyances are needed, such as in areas with highly erodible soils and slopes of less than 5 percent. They should be installed only where space is available for a relatively large cross-section. Grassed channels have a limited ability to control runoff from large storms and should not be used in areas where velocity exceeds 5 feet per second unless they are on erosion-resistant soils with dense groundcover at the soil surface.

**Design and Installation Criteria**

Because of their ease of construction and low cost, vegetation-lined waterways are frequently used for diversion and collection ditches. USDA's Soil Conservation Service's (SCS) *Engineering Field Manual* (1979) recommends the maximum permissible velocities for individual site conditions shown in Table 5-5.

**Table 5-5. Maximum Permissible Velocities for Individual Site Conditions for Grass Swales**

| Site Location | Velocity |
|---|---|
| Areas where only a sparse cover can be established or maintained because of shale, soils, or climate | 3.00 ft/sec (0.91 m/sec) |
| If the vegetation is to be established by seeding | 3.00 to 4.00 ft/sec (0.91 to 1.22 m/sec) |
| Areas where a dense, vigorous sod is obtained quickly or where the runoff can be diverted out of the waterway while the vegetation is being established | 4.00 to 5.00 ft/sec (1.22 to 1.52 m/sec) |

Source: USDA, 1979

Grassed waterways typically begin eroding in the invert of the channel if the velocity exceeds the sheer strength of the vegetation soil interface. Once the erosion process has started, it will continue until an erosion-resistant layer is encountered. If erosion of a channel bottom is occurring, rock or stone should be placed in the eroded area or the design should be changed (UNEP, 1994).

Grassed waterways on construction land must be able to carry peak runoff events from snowmelt and rainstorms (in some areas limited to up to 1 cubic meter of water per second). The size of the waterway depends on the size of the area to be drained. A typical grassed waterway cross-section is parabolic with a nearly flat-bottom, a bottom width of 3 m, and channel depth of at least 30 cm. Side slopes usually rise about 1 m for every 10 m horizontal distance but may be as steep as a 1 m rise for every 2 m of horizontal distance. The waterway should follow the natural drainage path if possible (Vanderwel and Abday, 1998). The design should be site-specific and be derived using well-established procedures.

Lined channels are a means of carrying water to lower elevations along steep parts of a waterway. Those portions of the waterway are precisely shaped and carefully lined with heavy-duty erosion control matting (a geotextile product). The lining is covered with a layer of soil and seeded to grass. The resulting channel is highly resistant to erosion. Lined channels are appropriate for waterways that only carry water occasionally and have slopes of up to 10 percent. Companies that sell geotextile products provide detailed information on installation of their products (Vanderwel and Abday, 1998). The design should be site-specific and be derived using well-established procedures. No standard procedure is available for evaluating the effectiveness of geotextile liners for pollutant removal.

Grass-lined channels should be sited in accordance with the natural drainage system and should not cross ridges. The channel design should not have sharp curves or significant changes in slope. The channel should not receive direct sedimentation from disturbed areas and should be sited only on the perimeter of a construction site to convey relatively clean storm water runoff. They should be separated from disturbed areas by a vegetated buffer or other BMP to reduce sediment loads.

Although exact design criteria should be based on local conditions, basic design recommendations for grassed channels include the following:

- Construction and vegetation of the channel should occur before grading and paving activities begin.

- Design velocities should be less than 5 ft/sec.

- Geotextiles can be used to stabilize vegetation until it is fully established.

- Covering the bare soil with sod or geotextiles can provide reinforced storm water conveyance immediately.

- Triangular-shaped channels should be used with low velocities and small quantities of runoff; parabolic grass channels are used for larger flows and where space is available; trapezoidal channels are used with large flows of low velocity (low gradient).

- Outlet stabilization structures might be needed if the runoff volume or velocity has the potential to exceed the capacity of the receiving area.

- Channels should be designed to convey runoff from a 10-year storm without erosion.

- The sides of the channel should be sloped less than 3:1, with V-shaped channels along roads sloped 6:1 or less for safety.

- All trees, bushes, stumps, and other debris should be removed during construction.

**Effectiveness**

Grass-lined channels can effectively transport storm water from construction areas if they are designed for expected flow volumes and velocities and if they do not receive sediment directly from disturbed areas. The primary function is to carry the flow at a higher velocity without eroding or overtopping the channel.

**Limitations**

Grassed channels, if improperly installed, can alter the natural flow of surface water and have adverse impacts on downstream waters. Additionally, if the design capacity is exceeded by a large storm event, the vegetation might not be sufficient to prevent erosion and the channel might be destroyed. Clogging with sediment and debris reduces the effectiveness of grass-lined channels for storm water conveyance.

**Maintenance**

Maintenance requirements for grass channels are relatively minimal. During the vegetation establishment period, the channels should be inspected after every rainfall. Other maintenance activities that should be carried out after vegetation is established are mowing, litter removal, and spot vegetation replacement. The most important objective in the maintenance of grassed channels is the maintaining of a dense and vigorous growth of turf. Periodic cleaning of vegetation and soil buildup in curb cuts is required so that water flow into the channel is unobstructed. During the growing season, channel grass should be cut no shorter than the level of design flow, and the cuttings should be removed promptly.

**Cost**

Costs of grassed channels range according to depth, with a 1.5-foot-deep, 10-foot-wide grassed channel estimated to cost between $6,395 and $17,075 per trench, while a 3.0-foot-deep, 21-foot-wide grassed channel is estimated at $12,909 to $33,404 per trench (SWRPC, 1991).

As an alternative cost approximation, grassed channel construction costs can be developed using unit cost values. Shallow trenching (1 to 4 feet deep) with a backhoe in areas not requiring dewatering can be performed for $4 to $5 per cubic yard of removed material (R. S. Means, 2000). Assuming no disposal costs (i.e., excavated material is placed on either side of the trench), only the cost of fine grading, soil treatment, and grassing (approximately $2 per square yard of earth surface area) should be added to the trenching cost to approximate the total construction cost. Site-specific hydrologic analysis of the construction site is necessary to estimate the channel conveyance requirement, however, it is not unusual to have flows on the order of 2 to 4 cfs per acre served. For channel velocities between 1 and 3 feet per second, the resulting range in the channel cross-section area can be as low as 0.67 square foot per acre drained to as high as 4 square feet per acre. If the average channel flow depth is 1 foot, then the low estimate for grassed channel installation is $0.27 per square foot of channel bottom per acre served per foot of channel length. The high estimate is $1.63 per square foot of channel bottom per acre served per foot of channel length.

### 5.1.5.1.2.2 Seeding

**General Description**

Permanent seeding, is used to control runoff and erosion on disturbed areas by establishing perennial vegetative cover from seed. It is used to reduce erosion, decrease sediment yields from disturbed areas, and provide permanent stabilization. This practice is both economical and adaptable to different site conditions, and it allows selection of the most appropriate plant materials. Seeding is a best management practice that is particularly susceptible to local conditions such as the climatic conditions, physical and chemical characteristics of the soil, topography, and time of year.

### Applicability

Permanent seeding is well-suited in areas where permanent, long-lived vegetative cover is the most practical or most effective method of stabilizing the soil. Permanent seeding can be used on roughly graded areas that will not be regraded for at least a year. Vegetation controls erosion by protecting bare soil surfaces from displacement by raindrop impacts and by reducing the velocity and quantity of overland flow. The advantages of seeding over other means of establishing plants include lower initial costs and labor inputs.

### Design and Installation Criteria

Areas to be stabilized with permanent vegetation must be seeded or planted 1 to 4 months after the final grade is achieved unless temporary stabilization measures are in place. Successful plant establishment can be maximized with proper planning; consideration of soil characteristics; selection of plant materials that are suitable for the site; adequate seedbed preparation, liming, and fertilization; timely planting; and regular maintenance. Climate, soils, and topography are major factors that dictate the suitability of plants for a particular site. The soil on a disturbed site might require amendments to provide sufficient nutrients for seed germination and seedling growth. The surface soil must be loose enough for water infiltration and root penetration. Soil pH should be between 6.0 and 6.5 and can be increased with liming if soils are too acidic. Seeds can be protected with mulch to retain moisture, regulate soil temperatures, and prevent erosion during seedling establishment.

Seedbed preparation is critical in established vegetation. Spraying seeds on a scraped slope will generally not provide satisfactory results. Typical seedbed preparation will begin with a soil test to determine the amount of lime or fertilizer that should be added. In addition, tillage should be performed that will break up clods so that seed contact can be established. When the seed is applied, it should be covered and lightly compacted. A natural or synthetic mulch is recommended to provide surface stabilization until the vegetation is established. In addition to providing surface stabilization, the mulch will also retard evaporation and encourage rapid growth. A suitable tack to hold the mulch may be necessary if the mulch is not otherwise anchored. Mulch as an erosion control practice is covered in a subsequent sub-section.

Depending on the amount of use permanently seeded areas receive, they can be considered high- or low-maintenance areas. High-maintenance areas are mowed frequently, limed and fertilized regularly, and either (1) receive intense use (for example, athletic fields) or (2) require maintenance to an aesthetic standard (for example, home lawns). Grasses used for high-maintenance areas are long-lived perennials that form a tight sod and are fine-leaved. High-maintenance vegetative cover is used for homes, industrial parks, schools, churches, and recreational areas.

Low-maintenance areas are mowed infrequently or not at all and do not receive lime or fertilizer on a regular basis. Plants must be able to persist with minimal maintenance over long periods of time. Grass and legume mixtures are favored for these sites because legumes fix nitrogen from the atmosphere. Sites suitable for low-maintenance vegetation include steep slopes, streambanks or channel banks, some commercial properties, and "utility" turf areas such as road banks.

**Effectiveness**

Seeding that results in a successful stand of grass has been shown to remove between 50 and 100 percent of total suspended solids from storm water runoff, with an average removal of 90 percent (USEPA, 1993).

**Limitations**

The effectiveness of permanent seeding can be limited because of the high erosion potential during establishment, the need to reseed areas that fail to establish, limited seeding times depending on the season, and the need for stable soil temperature and soil moisture content during germination and early growth. Permanent seeding does not immediately stabilize soils—temporary erosion and sediment control measures should be in place to prevent off-site transport of pollutants from disturbed areas. Use of mulches and/or geotextiles may improve the likelihood of successfully establishing vegetation.

**Maintenance**

Grasses should emerge within 4 to 28 days and legumes within 5 to 28 days after seeding. A successful stand should exhibit the following:

- Vigorous dark green or bluish green seedlings—not yellow
- Uniform density, with nurse plants, legumes, and grasses well intermixed
- Green leaves—perennials remaining throughout the summer, at least at the plant bases

Seeded areas should be inspected for failure, and necessary repairs and reseeding should be made as soon as possible. If a stand has inadequate cover, the choice of plant materials and quantities of lime and fertilizer should be reevaluated. Depending on the condition of the stand, areas can be repaired by overseeding or reseeding after complete seedbed preparation. If the timing is bad, an annual grass seed can be overseeded to temporarily thicken the stand until a suitable time for seeding perennials. Consider seeding temporary, annual species if the season is not appropriate for permanent seeding. If vegetation fails to grow, the soil should be tested to determine whether low pH or nutrient imbalances are responsible. Local NRCS or county extension agents can also be contacted for seeding and soil testing recommendations.

On a typical disturbed site, full plant establishment usually requires refertilization in the second growing season. Soil tests should be used to determine whether more fertilizer needs to be added. Do not fertilize cool season grasses in late May through July. Grass that looks yellow may be nitrogen deficient. Nitrogen fertilizer should not be used if the stand contains more than 20 percent legumes.

**Cost**

Seeding costs range from $200 to $1,000 per acre and average $400 per acre. Maintenance costs range from 15 to 25 percent of initial costs and average 20 percent (USEPA, 1993). R. S. Means (2000) indicates the cost of mechanical seeding to be approximately $900 per acre, and demonstrates that the coverage cost varies with the seed type, seeding approach and scale (total acreage to be seeded). For example, hydro or water-based seeding for grass is estimated to be $700 per acre, but seeding of “field” grass species is only $540 per acre (Costs include materials, labor, and equipment, with profit and overhead). If surface preparation is required, then the installation costs increase. R. S. Means suggests the cost of fine grading, soil treatment, and grassing is approximately $2 per square yard.

#### 5.1.5.1.2.3 Sodding

**General Description**

Sodding is a permanent erosion control practice that involves laying a continuous cover of grass sod on exposed soils. In addition to stabilizing soils, sodding can reduce the velocity of storm water runoff. Sodding can provide immediate vegetative cover for critical areas and stabilize areas that cannot be vegetated by seed. It can also stabilize channels or swales that convey concentrated flows and reduce flow velocities. While sodding is not as dependent as seeding on local conditions, it does depend on soil and climatic conditions to be successful. Watering immediately after installation and occasionally until establishment is generally beneficial.

**Applicability**

Sodding is appropriate for any graded or cleared area that might erode, requiring immediate vegetative cover. Locations particularly well-suited to sod stabilization are:

- Waterways and channels carrying intermittent flow
- Areas around drop inlets that require stabilization
- Residential or commercial lawns and golf courses where prompt use and aesthetics are important
- Steeply sloped areas

## Design and Installation Criteria

Sodding eliminates the need for seeding and mulching and produces more reliable results with less maintenance. Sod can be laid during times of the year when seeded grasses can fail. The sod must be watered frequently within the first few weeks of installation. Some seedbed preparation is recommended, including smoothing to provide contact between the sod and the soil surface and soil testing to determine liming and fertilizer application rates. Since sod provides instantaneous cover, mulches are not typically recommended, but anchoring may be appropriate on steep slopes.

The type of sod selected should be composed of plants adapted to site conditions. Sod composition should reflect environmental conditions as well as the function of the area where the sod will be laid. The sod should be of known genetic origin and be free of noxious weeds, diseases, and insects. The sod should be machine cut at a uniform soil thickness of 15 to 25 mm at the time of establishment (this does not include top growth or thatch). Soil preparation and addition of lime and fertilizer may be needed—soils should be tested to determine whether amendments are needed. Sod should be laid in strips perpendicular to the direction of water flow and staggered in a brick-like pattern. The corners and middle of each strip should be stapled firmly. Jute or plastic netting may be pegged over the sod for further protection against washout during establishment.

Areas to be sodded should be cleared of trash, debris, roots, branches, stones, and clods larger than 2 inches in diameter. Sod should be harvested, delivered, and installed within a period of 36 hours. Sod not transplanted within this period should be inspected and approved prior to its installation.

## Limitations

Compared to seed, sod is more expensive and more difficult to obtain, transport, and store. Care must be taken to prepare the soil and provide adequate moisture before, during, and after installation to ensure successful establishment. If sod is laid on poorly prepared soil or unsuitable surface, the grass will die quickly because it is unable to root. Sod that is not adequately irrigated after installation may cause root dieback because grass does not root rapidly and is subject to drying.

## Effectiveness

Sod has been shown to remove between 98 and 99 percent of total suspended solids in runoff (USEPA, 1993). It is therefore a highly effective management practice for erosion and sediment control.

## Maintenance

Watering is very important to maintain adequate moisture in the root zone and to prevent dormancy, especially within the first few weeks of installation, until it is fully rooted. Mowing should not result in the removal of more than one-third of the shoot. Grass height should be maintained to be 2–3 inches long. After the first growing season, sod might require fertilization or liming.

Permanent, fine turf areas require yearly fertilization. Warm-season grass should be fertilized in late spring to early summer, and cool-season grass in late winter and again in early fall.

**Cost**

Average installation costs of sod average $0.20 per square foot and range from $0.10 to $1.10 per square foot; maintenance costs are approximately 5 percent of installation costs (USEPA, 1993). R. S. Means (2000) indicates the sodding ranges between $250 and $750 per 1000 square feet for 1" deep bluegrass sod on level ground, depending on the size of the area treated (unit costs value are for orders over 8,000 square feet and less than 1000 square feet, respectively). Bent grass sod values range between $350 and $500 per 1,000 square feet; again the lower value is more likely for most construction sites because it is for large area applications. (Costs include materials, labor, and equipment, with profit and overhead).

### 5.1.5.1.2.4 Mulching

**General Description**

Mulching is a temporary erosion control practice in which materials such as grass, hay, wood chips, wood fibers, straw, or gravel are placed on exposed or recently planted soil surfaces. Mulching is highly recommended as a stabilization method and is most effective when anchored in place until vegetation is well established. In addition to stabilizing soils, mulching can reduce the velocity of storm water runoff. When used in combination with seeding or planting, mulching can aid plant growth by holding seeds, fertilizers, and topsoil in place; by preventing birds from eating seeds; by retaining moisture; and by insulating plant roots against extreme temperatures.

Mulch mattings are materials such as jute or other wood fibers that are formed into sheets and are more stable than loose mulch. They can also be easily unrolled during the installation process and are particularly useful in steeper areas or in channels. Netting can be used to stabilize soils while plants are growing, although netting does not retain moisture or insulate against extreme temperatures. Mulch binders consist of asphalt or synthetic materials that are sometimes used instead of netting to bind loose mulches, but these have been found to have limited usefulness.

**Applicability**

Mulching is often used in areas where temporary seeding cannot be used because of environmental constraints. Mulching can provide immediate, effective, and inexpensive erosion control. On steep slopes and critical areas such as waterways, mulch matting is used with netting or anchoring to hold it in place. Mulches can be used on seeded and planted areas where slopes are steeper than 2:1 or where sensitive seedlings require insulation from extreme temperatures.

### Design and Installation Criteria

When possible, organic mulches should be used for erosion control and plant material establishment. Suggested materials include loose straw, netting, wood cellulose, or agricultural silage. All materials should be free of seed, and loose hay or straw should be anchored by applying tackifier, stapling netting over the top, or crimping with a mulch crimping tool. Materials that are heavy enough to stay in place do not need anchoring (for example, gravel). Steepness of the slope will also affect the extent of anchoring the mulch. Other examples include hydraulic mulch products with 100 percent post-consumer paper content, yard trimming composts, and wood mulch from recycled stumps and tree parts. Inorganic mulches such as pea gravel or crushed granite can be used in unvegetated areas.

Mulches may or may not require a binder, netting, or tacking. All straw and loose materials must have a binder to hold them in place. Mulch materials that float away during storms can clog drainage ways and lead to flooding. The extent of binding depends on the type of mulch applied. Effective use of netting and matting material requires firm, continuous contact between the materials and the soil. If there is no contact, the material will not hold the soil and erosion will occur underneath the material. Grading is not necessary before mulching.

There must be adequate coverage, or erosion, washout, and poor plant establishment will result. If an appropriate tacking agent is not applied, or if it is applied in an insufficient amount, mulch will not withstand wind and runoff. The channel grade and liner must be appropriate for the amount of runoff, or the channel bottom will erode. Also, hydromulch should be applied in spring, summer, or fall to prevent deterioration of the mulch before plants can become established. Table 5-6 presents guidelines for installing mulches, but local conditions may warrant additional requirements.

**Table 5-6. Typical Mulching Materials and Application Rates**

| Material | Rate per Acre | Requirements | Notes |
|---|---|---|---|
| **Organic Mulches** | | | |
| Straw | 1-2 tons | Dry, unchopped, unweathered; avoid weeds. | Spread by hand or machine; must be tacked or tied down. |
| Wood fiber or wood cellulose | 0.5-1 ton | | Use with hydroseeder; may be used to tack straw. Do not use in hot, dry weather. |
| Wood chips | 5-6 tons | Air dry. Add fertilizer N, 12 lb/ton. | Apply with blower, chip handler, or by hand. Not for fine turf areas. |
| Bark | 35 $yd^3$ | Air dry, shredded or hammermilled, or chips. | Apply with mulch blower, chip handler, or by hand. Do not use asphalt tack. |
| **Nets and Mats** | | | |
| Jute net | Cover area | Heavy, uniform; woven of single jute yarn. Used with organic mulch. | Withstands water flow. |
| Excelsior (wood fiber) mat | Cover area | | |
| Fiberglass roving | 0.5-1 ton | Continuous fibers of drawn glass bound together with a non-toxic agent. | Apply with compressed air ejector. Tack with emulsified asphalt at a rate of 25-35 gal/1,000 $ft^2$. |

**Effectiveness**

Mulching effectiveness varies with the type of mulch used and local conditions such as rainfall and runoff amounts. Percent soil loss reduction for different mulches ranges from 53 to 99.8 percent and associated water velocity reductions range from 24 to 78 percent (Harding, 1990). Table 5-7 shows soil loss and water velocity reductions for different mulch treatments.

**Table 5-7. Measured Reductions in Soil Loss for Different Mulch Treatments**

| Mulch characteristics | Soil loss reduction (%) | Water velocity reduction (%) relative to bare soil |
|---|---|---|
| 100% wheat straw/top net | 97.5 | 73 |
| 100% wheat straw/two nets | 98.6 | 56 |
| 70% wheat straw/30% coconut fiber | 98.7 | 71 |
| 70% wheat straw/30% coconut fiber | 99.5 | 78 |
| 100% coconut fiber | 98.4 | 77 |
| Nylon monofilament/two nets | 99.8 | 74 |
| Nylon monofilament/rigid/bonded | 53.0 | 24 |
| Vinyl monofilament/flexible/bonded | 89.6 | 32 |
| Curled wood fibers/top net | 90.4 | 47 |
| Curled wood fibers/two nets | 93.5 | 59 |
| Antiwash netting(jute) | 91.8 | 59 |
| Interwoven paper and thread | 93.0 | 53 |
| Uncrimped wheat straw–2,242 kg/ha | 84.0 | 45 |
| Uncrimped wheat straw–4,484 kg/ha | 89.3 | 59 |

Source: Harding, 1990, as cited in USEPA, 1993.

### Limitations

Mulching, matting, and netting might delay seed germination because the cover changes soil surface temperatures. The mulches themselves are subject to erosion and may be washed away in a large storm if not sufficiently anchored with netting or tacking. Maintenance is necessary to ensure that mulches provide effective erosion control.

### Maintenance

Mulches must be anchored to resist wind displacement. Netting should be removed when protection is no longer needed and disposed of in a landfill or composted. Mulched areas should be inspected frequently to identify areas where mulch has loosened or been removed, especially after rain storms. Such areas should be reseeded (if necessary) and the mulch cover replaced immediately. Mulch binders should be applied at rates recommended by the manufacturer. If washout, breakage, or erosion occurs, surfaces should be repaired, reseeded, and remulched, and new netting should be installed. Inspections should be continued until vegetation is firmly established.

**Cost**

The costs of seed and mulch average $1,500 per acre and range from $800 to $3,500 per acre (USEPA, 1993). R. S. Means (2000) estimates the cost of power mulching to be $22.50 per 1,000 square feet, for large volume applications. In addition, hydro- and mechanical seeding are approximately $700 to $900 per acre. Coverage cost varies with the seed type, seeding approach, and scale (total acreage to be seeded). For example, hydro or water-based seeding for grass is estimated to cost $700 per acre, but seeding of "field" grass species is only $540 per acre. (Costs include materials, labor, and equipment, with profit and overhead.) If surface preparation is required, then the installation costs increase. R. S. Means (2000) suggests the cost of fine grading, soil treatment, and grassing is approximately $2 per square yard of earth surface area.

#### 5.1.5.1.2.5 Geotextiles

**General Description**

Geotextiles are porous fabrics also known as filter fabrics, road rugs, synthetic fabrics, construction fabrics, or simply fabrics. Geotextiles are manufactured by weaving or bonding fibers made from synthetic materials such as polypropylene, polyester, polyethylene, nylon, polyvinyl chloride, glass, and various mixtures of these materials. As a synthetic construction material, geotextiles are used for a variety of purposes such as separators, reinforcement, filtration and drainage, and erosion control (USEPA, 1992). Some geotextiles are made of biodegradable materials such as mulch matting and netting. Mulch mattings are jute or other wood fibers that have been formed into sheets and are more stable than normal mulch. Netting is typically made from jute, wood fiber, plastic, paper, or cotton and can be used to hold the mulching and matting to the ground. Netting can also be used alone to stabilize soils while the plants are growing; however, it does not retain moisture or temperature well.

Geotextiles can aid in plant growth by holding seeds, fertilizers, and topsoil in place. Fabrics are relatively inexpensive for certain applications—a wide variety of geotextiles exist to match the specific needs of the site.

**Applicability**

Geotextiles can be used for erosion control by using it alone. Geotextiles can be used as matting, which is used to stabilize the flow of channels or swales or to protect seedlings on recently planted slopes until they become established. Matting may be used on tidal or streambanks where moving water is likely to wash out new plantings. They can also be used to protect exposed soils immediately and temporarily, such as when active piles of soil are left overnight.

Geotextiles are also used as separators. An example of such a use is geotextile as a separator between riprap and soil. This "sandwiching" prevents the soil from being eroded from beneath the riprap and maintaining the riprap's base.

**Design and Installation Criteria**

Many types of geotextiles are available. Therefore, the selected fabric should match its purpose. State or local requirements, design procedures, and any other applicable requirements should be considered. In the field, important concerns include regular inspections to determine whether cracks, tears, or breaches are present in the fabric and to identify when repairs should be made. Effective netting and matting require firm, continuous contact between the materials and the soil. If there is no contact, the material will not hold the soil and erosion will occur underneath the material.

**Effectiveness**

A geotextile's effectiveness depends upon the strength of the fabric and proper installation. For example, when protecting a cut slope with a geotextile, it is important to properly anchor the fabric using appropriate length and spacing of wire staples. This will ensure that it will not be undermined by a storm event.

**Limitations**

Geotextiles (primarily synthetic types) have the potential disadvantage of being sensitive to light and must be protected prior to installation. Some geotextiles might promote increased runoff and might blow away if not firmly anchored. Depending on the type of material used, geotextiles might need to be disposed of in a landfill, making them less desirable than vegetative stabilization. If the fabric is not properly selected, designed, or installed, the effectiveness may be reduced drastically.

**Maintenance**

Regular inspections should be made to determine whether cracks, tears, or breaches have formed in the fabric—it should be repaired or replaced immediately. It is necessary to maintain contact between the ground and the geotextile at all times.

**Cost**

Costs for geotextiles range from $0.50 to $10.00 per square yard depending on the type chosen (SWRPC, 1991). Geosynthetic turf reinforcement mattings (TRMs) are widely used for immediate erosion protection and long-term vegetative reinforcement, usually for steeply sloped areas or areas exposed to runoff flows. The Erosion Control Technology Council (a geotextile industry support association) estimates TRMs cost approximately $7.00 per square yard (installed) for channel protection (ECTC, 2002a). Channel protection is one of the most demanding of installations (much more demanding than general coverage of denuded area). The ECTC (2002b) estimates the cost to install a simple soil blanket (or rolled erosion control product), seed, and fertilizer to be $1.00 per square yard.

#### 5.1.5.1.2.6 Vegetated Buffer Strips

**General Description**

Vegetated buffers are areas of either natural or established vegetation that are maintained to protect the water quality of neighboring areas. Buffer zones reduce the velocity of storm water runoff, provide an area for the runoff to permeate the soil, allow ground water recharge, and act as filters to catch sediment. The reduction in velocity also helps to prevent soil erosion.

**Applicability**

Vegetated buffers can be used in any area that is able to support vegetation, but they are most effective and beneficial on floodplains, near wetlands, along streambanks, and on steep, unstable slopes. They are also effective in separating land use areas that are not compatible and in protecting wetlands or waterbodies by displacing activities that might be potential sources of nonpoint source pollution.

**Design and Installation Criteria**

To establish an effective vegetative buffer, the following guidelines should be followed:

- Soils should not be compacted.
- Slopes should be less than 5 percent.
- Buffer widths should be determined after careful consideration of slope, vegetation, soils, depth to impermeable layers, runoff sediment characteristics, type and quantity of storm water pollutants, and annual rainfall.
- Buffer widths should increase as slope increases.
- Zones of vegetation (native vegetation in particular), including grasses, deciduous and evergreen shrubs, and understory and overstory trees, should be intermixed.
- In areas where flows are concentrated and velocities are high, buffer zones should be combined with other structural or nonstructural BMPs as a pretreatment.

Vegetated strips have been studied extensively, with emphasis placed on their effectiveness in removing sediment and other pollutants. Vegetated strips are most appropriate at sites where sediment loads are relatively low, as high sediment loads will cause large quantities of deposition along the leading edge of the vegetation. This deposition will cause the flow to divert around the vegetation in a concentrated flow pattern, which will cause short-circuiting and greatly reduce removal efficiency. Variability in vegetation density and uniformity often causes similar problems. Removal efficiency depends on a combination of slope, length, and width of the filter; density of the vegetation; sediment characteristics, hydraulics of the flow; and infiltration. The interaction of these variables is complex and prevents the process from being reduced to a simple relationship except on a local basis. For site-specific local conditions, methods have been developed that allow trapping to be related to strip length and slope.

**Effectiveness**

Considerable data have been collected on the effectiveness of buffer strips for specific conditions. Numerous factors such as infiltration rate, flow depth, slope, dimensions of the buffer, density and type of vegetation, sediment size, and sediment density impact removal rates. Recent studies show that even short vegetative buffers can trap high percentages of sediment and certain chemicals. A significant concern is whether flow is allowed to concentrate, which will greatly reduce the travel time through the buffer and prevent the removal of pollutants.

Several researchers have measured greater than 90 percent reductions in sediment and nitrate concentrations; buffer/filter strips do a reasonably good job of removing phosphorus attached to sediment, but are relatively ineffective in removing dissolved phosphorus (Gillman, 1994). However, since the hydraulics of flow through buffer strips are not well defined and can vary considerably based on site conditions, it is difficult to consistently estimate the effectiveness of buffer strips.

**Limitations**

Vegetated buffers require plant growth before they can be effective, and land must be available on which to plant the vegetation.  If land costs are very high, buffer zones might not be cost-effective. Although vegetated buffers help to protect water quality, they usually do not effectively mitigate concentrated storm water flows to neighboring or downstream wetlands.

**Maintenance**

Keeping the vegetation in vegetated buffers healthy requires routine maintenance, which (depending on species, soil types, and climatic conditions) can include weed and pest control, mowing, fertilizing, liming, irrigating, and pruning.  Inspection and maintenance are most important when buffer areas are first installed.  Once established, vegetated buffers do not require much maintenance beyond the routine procedures listed earlier and periodic inspections of the areas, especially after any heavy rainfall and at least once a year.  Inspections should focus on encroachment, gully erosion, density of vegetation, evidence of concentrated flows through the areas, and any damage from foot or vehicular traffic. If there are more than 6 inches of sediment in one place, it should be removed.

**Cost**

Conceptual cost estimates for grassed buffer strips can be made based on square footage using unit cost values. R. S. Means (2000) estimates the cost of fine grading, soil treatment, and grassing to be $2 per square yard. This cost estimate is based on application of traditional lawn seed. The cost for field seed is lower than lawn seed, reducing the coverage price. Where gently sloping areas just need to be grassed with acceptable species, the cost can be as low as $0.38 per square yard.

#### 5.1.5.1.2.7 Erosion Control Matting

**General Description**

Erosion control mats can be either organic or made from a synthetic material. A wide variety of products exist to match the specific needs of the site. Organic mats are made from such materials as wood fiber, jute net, and coconut coir fiber. Unlike organic matter, synthetic mats are constructed from non-biodegradable materials and remain in place for many years. These organic mats are classified as Turf Reinforcement Mats (TRMs) and Erosion Control and Revegetation Mats (ECRMs) (USDOT, 1995).

Erosion control matting aids in plant growth by holding seeds, fertilizers, and topsoil in place. Matting can be used to stabilize the flow of channels or swales or to protect seedlings on recently planted slopes until they become established. Matting can be used on tidal or streambanks where moving water is likely to wash out new plantings. It can also be used to protect exposed soils immediately and temporarily, such as when active piles of soil are left overnight.

**Applicability**

Mulch mattings, netting, and filter fabrics are particularly useful in steep areas and drainage swales where loose seed is vulnerable to being washed away or failing to survive dry soil (UNEP, 1994). Erosion control mats can also be used to separate riprap and soil. This results in a “sandwiching” effect, maintaining the riprap’s base and preventing the soil beneath from being eroded.

**Design and Installation Criteria**

Matting is especially recommended for steep slopes and channels (UNEP, 1994).

Many types of erosion control mats are available. Therefore, the selected product should match its purpose. Effective netting and matting require firm, continuous contact between the materials and the soil. If there is no contact, the material will not hold the soil and erosion will occur underneath the material.

*Wood fiber* or curled wood mat consists of curled wood with fibers, 80 percent of which are 150 mm or longer, with a consistent thickness and even distribution of fiber over the entire mat. The top side of the mat is covered with a biodegradable plastic mesh. The mat is placed in the channel or on the slope parallel to the direction of flow and secured with staples and check slots. This is applied immediately after seeding operations (USDOT, 1995).

*Jute net* consists of jute yarn, approximately 5 mm in diameter, woven into a net with openings that are approximately 10 by 20 mm (or 0.40 to 0.79 inches). The jute net is loosely laid in the channel parallel to the direction of flow. The net is secured with staples and check slots at intervals along the channel. Placement of the jute net is done immediately after seeding operations (USDOT, 1995).

*Coconut blankets* are constructed of biodegradable coconut fibers that resist decay for 5 to 10 years to provide long, temporary erosion control protection. The materials are often encased in ultraviolet stabilized nets and sometimes have a composite, polypropylene structure to provide permanent turf reinforcement. These materials are best used for waterway stabilization and slopes that require longer periods to stabilize (USDOT, 1995).

Within the synthetic mat category are TRMs and ECRMs. *Turf reinforcement mats* are three-dimensional polymer nettings or monofilaments formed into a mat. They have sufficient thickness (>13 mm or 0.5 inch) and void space (>90 percent) to allow for soil filling and retention. The mat acts as a traditional mat to protect the seed and increase germination. As the turf establishes, the mat remains in place as part of the root structure. This gives the established turf a higher strength and resistance to erosion (USDOT, 1995).

*Erosion control and revegetation mats* are composed of continuous monofilaments bound by heat fusion or stitched between nettings. They are thinner than TRMs and do not have the void space to allow for filling of soil. They act as a permanent mulch and allow vegetation to grow through the mat (USDOT, 1995).

**Effectiveness**

The effectiveness of erosion control matting depends upon the strength of the material and proper installation. For example, when protecting a cut slope with an erosion control mat, it is important to anchor the mat properly. This will ensure that it will not be undermined by a storm event.

While erosion control blankets can be effective, their performance varies. Some general trends are that organic materials tend to be the most effective (Harding, 1990) and that thicker materials are typically superior (Fifield, 1992), but there are exceptions to both of these trends. Information about product testing of blankets is generally lacking. One notable exception is the Texas Department of Transportation, which publishes the findings of their testing program in the form of a list of acceptable and unacceptable materials for specific uses.

**Limitations**

Erosion control mats (primarily synthetic types) are sensitive to light and for this reason must be protected prior to installation. Some erosion control mats might cause an increase in runoff or blow away if not firmly anchored. Erosion control mats might need to be properly disposed of in a landfill, depending on the type of material. Effectiveness may be reduced if the fabric is not properly selected, designed, or installed.

**Maintenance**

Regular inspections are necessary to determine whether cracks, tears or breaches have formed in the fabric. Contact between the ground and erosion control mat should be maintained at all times and trapped sediment removed after each storm event.

**Cost**

Costs for erosion control mats range from \$0.50 to \$10.00 per square yard depending on the type chosen (SWRPC, 1991). Geosynthetic turf reinforcement mattings are widely used for immediate erosion protection and long-term vegetative reinforcement, usually for steeply sloped areas or areas exposed to runoff flows. The Erosion Control Technology Council (a geotextile industry support association) estimates that TRMs cost approximately \$7.00 per square yard (installed) for channel protection (ECTC, 2002a). Channel protection is one of the most demanding of installations (much more demanding than general coverage of denuded area). The ECTC estimates the cost to install a simple soil blanket (or rolled erosion control product), seed, and fertilizer to be \$1.00 per square yard (ECTC, 2002b).

### 5.1.5.1.2.8 Topsoiling

**General Description**

Topsoiling is the placement of a surface layer of soil enriched in organic matter over a prepared subsoil to provide a suitable soil medium for vegetative growth on areas with poor moisture, low nutrient levels, undesirable pH, and/or the presence of other materials that would inhibit the establishment of vegetation. Advantages of topsoil include its high organic matter content and friable consistency and its water-holding capacity and nutrient content. The texture and friability of topsoil are usually more conducive to seedling emergence and root growth. In addition to being a better growth medium, topsoil is often less erodible than subsoils, and the coarser texture of topsoil increases infiltration capacity and reduces runoff. During construction, topsoil is often removed from the project area and stockpiled. It is replaced on areas to be grassed or landscaped during the final stages of the project.

**Applicability**

Conditions where topsoiling applies include the following:

- Where a sufficient supply of quality topsoil is available.

- Where the subsoil or areas of existing surface soil present the following problems:
  - The structure, pH, or nutrient balance of the available soil cannot be amended by reasonable means to provide an adequate growth medium for the desired vegetation.
  - The soil is too shallow to provide adequate rooting depth or will not supply necessary moisture and nutrients for growth of desired vegetation.
  - The soil contains substances toxic to the desired vegetation.

- Where high quality turf or ornamental plants are desired.

- Where slopes are 2:1 or flatter.

**Design and Installation Criteria**

The topsoil should be uniformly distributed over the subsoil to a minimum compacted depth of 50 mm (2 inches) on slopes steeper than 3:1 and 100 mm (4 inches) on flatter slopes. Thicknesses of 100 to 150 mm is preferred for vegetation establishment via seeding. The topsoil should not be placed while in a frozen or muddy condition or when the subsoil is excessively wet, frozen, or in a condition that is detrimental to proper grading or seedbed preparation. The final surface should be prepared so that any irregularities are corrected and depressions and water pockets do not form. If the topsoil has been treated with soil sterilants, it should not be placed until the toxic substances have dissipated (USDOT, 1995). Table 5-8 summarizes the cubic yards of topsoil required for application to various depths.

**Table 5-8. Cubic Yards of Topsoil Required for Application to Various Depths**

| Depth (inches) | Per 1,000 Sq Ft | Per Acre |
|---|---|---|
| 1 | 3.1 | 134 |
| 2 | 6.2 | 268 |
| 3 | 9.3 | 403 |
| 4 | 12.4 | 536 |
| 5 | 15.5 | 670 |
| 6 | 18.6 | 804 |

Source: Smolen et al., 1988.

On slopes and areas that will not be mowed, the surface may be left rough after spreading topsoil. A disk may be used to promote bonding at the interface between the topsoil and subsoil (Smolen et al., 1988).

**Effectiveness**

No information is available describing the effectiveness of applying topsoil as a BMP.

**Limitations**

Limitations of applying topsoil can include to following:

- Topsoil spread when conditions are too wet, resulting in severe compaction.
- Topsoil mixed with too much unsuitable subsoil material, resulting in poor vegetation establishment.
- Topsoil contaminated with soil sterilants or chemicals, resulting in poor or no vegetation establishment.
- Topsoil not adequately incorporated or bonded with the subsoil, resulting in poor vegetation establishment and soil slippage on sloping areas.
- Topsoiled areas not protected, resulting in excessive erosion.

**Maintenance**

Newly topsoiled areas should be inspected frequently until the vegetation is established. Eroded or damaged areas should be repaired and revegetated.

**Cost**

Topsoiling costs are a function of the price of topsoil, the hauling distance, and the method of application. R. S. Means (2000) report unit cost values of $3 and $4 per square yard, for 4 and 6 inches of topsoil cover, respectively. This price is for furnishing and placing of topsoil, and includes materials, labor, and equipment, with profit and overhead.

### 5.1.5.2 Water Handling Practices

#### 5.1.5.2.1 Earth Dike

**General Description**

An earth dike is a temporary or permanent ridge of soil designed to channel water to a desired location. Dikes are used to divert the flow of runoff by constructing a ridge of soil that intercepts and directs the runoff to the desired outlet or alternative management practice, such as a pond. This practice serves to reduce the length of a slope for erosion control and protect downslope areas. An earth dike can be used to prevent runoff from going over the top of a cut and eroding the slope, directing runoff away from a construction site or building; to divert clean water from a disturbed area; or to reduce a large drainage area into a more manageable size. Dikes should be stabilized with vegetation after construction (NAHB, No Date).

**Applicability**

Earth dikes are applicable to all areas; the size of the dike is correlated to the size of the drainage area (NAHB, No Date).

**Design and Installation Criteria**

The location of dikes should take into consideration outlet conditions, existing land use, topography, length of slope, soils, and development plans. The capacity of earth dikes and diversions should be suitable for the area that is being protected, including adequate freeboard, or extra depth that is added as a safety margin. For homes, schools, and industrial buildings, the recommended design frequency storm is 50 years and the freeboard is 0.5 feet (NAHB, No Date).

Earth dikes can be employed as a perimeter control. For small sites, a compacted 2-foot-tall dike is usually suitable, if hydroseeded. Larger dikes will actually divert runoff to another portion of the site, usually to a downstream sediment trap or basin. Therefore, the designer should ensure that they have the capacity for the 10-year storm event, and that the channel created behind the dike is properly stabilized to prevent erosion (Brown and Schueler, 1997). In addition, the downstream structure must be sized to handle the flow from the dike. Dikes should be designed using standard hydrologic and hydraulic calculations and certified by a professional hydrologist or engineer. Diversion dikes should be installed prior to the majority of the soil-disturbing activity. As soon as the dike form is completed, it should be machine compacted, fertilized, and either seeded and mulched or sodded. Excavated materials should be properly stockpiled for future use or disposed of properly. Dikes should have an outlet that functions with a minimum of erosion. Depending on site conditions and outlet structures, the runoff directed by dikes may need to be conveyed to a sediment-trapping device, such as a sediment basin or detention pond. As grades increase over 4 percent, geotextile material or sod may be required to control erosion. Slopes greater than 8 percent may require riprap. Dikes may be removed when stabilization of the drainage area and outlet are complete (NAHB, No Date). Dike design criteria must incorporate site-specific conditions, as dimensions depend on expected flows, soil types, and climatic conditions. All of these inputs vary tremendously over different sections of the country.

**Effectiveness**

No information has been found on the effectiveness of earth dikes used as BMPs, although terraces often have sediment removal rates of up to 90 percent.

**Limitations**

An erosion-resistant lining in the channel may be needed to prevent erosion in the channel caused by excessive grade. In addition, the channel should be deepened and the grade realigned if there is overtopping caused by sediment in the channel where the grade decreases or reverses. If overtopping occurs at low points in the ridge where the diversion crosses the shallow draw, the ridge should be reconstructed with a positive grade toward the outlet at all points. Finally, if there is erosion at the outlet, an outlet stabilization structure should be installed; if sedimentation occurs at the diversion outlet, a temporary sediment trap should be installed.

**Maintenance**

An earth dike should be inspected for signs of erosion after every major rain event. Any repairs and/or revegetation should be completed promptly (NAHB, No Date). The following actions can be taken to properly maintain an earth dike:

- Remove debris and sediment from the channel immediately after the storm event.
- Repair the dike to its original height.
- Check outlets and make necessary repairs to prevent gully formation.
- Clean out sediment traps when they are 50 percent full.
- Once the work area has been stabilized, remove the diversion ridge, fill and compact the channel to blend with the surrounding area, and remove sediment traps, disposing of unstable sediment in a designated area.

**Cost**

The cost of an earth dike depends on the design and materials used. Small dikes can cost approximately $2.00 per linear foot, while larger dikes can cost approximately $2.00 per cubic yard. EPA states that an earth dike can cost approximately $4.50 per linear foot (NAHB, No Date).

An alternative means to estimate conceptual costs for earthen dikes is to use unit cost values and a rough estimate of the quantities needed. Shallow trenching (1 to 4 feet deep) with a backhoe in areas not requiring dewatering can be performed for $4 to $5 per cubic yard of removed material (R. S. Means, 2000). Based on this value, $2 per linear foot provides for 11 square feet of flow area and $4.50 per linear foot provides for 24 square feet of flow area. This suggests that the size of the dike is required prior to specifying a cost, which requires a site-specific hydrologic evaluation. Based on standards for Virginia, most small drainage areas (made up of 5 acre or less) require 18-inch tall diversion dikes with a 4.5-foot base. Assuming the excavation volume equals the volume of the dike, the resulting excavation volume is approximately 7 cubic feet per linear foot, which (conservatively) equates to $1.03 to $1.30 per linear foot for construction costs.

If the earthen dikes are to be permanent, then additional costs are incurred to vegetate the dike. R. S. Means (2000) estimates the cost of fine grading, soil treatment, and grassing is approximately $2 per square yard of earth surface area. This adds approximately $6 per linear foot of dike. Where gently sloping areas just need to be grassed with acceptable species, the cost can be as low as $0.38 per square yard.

### 5.1.5.2.2 Temporary Swale

**General Description**

The term swale (grassed channel, dry swale, wet swale, biofilter) refers to a series of vegetated, open channel management practices designed specifically to treat and attenuate storm water runoff for a specified water quality volume. As storm water runoff flows through these channels, it is treated by filtering through the vegetation in the channel, filtering through a subsoil matrix, and/or infiltrating into the underlying soils. Variations of the grassed swale include the grassed channel, dry swale, and wet swale. The specific design features and methods of treatment differ in each of these designs, but all are improvements on the traditional drainage ditch and incorporate modified geometry and other features for use of the swale as a treatment and conveyance practice.

**Applicability**

Grassed swales can be applied in most situations with some restrictions and are very well suited for treating highway or residential road runoff because they are linear practices. Perimeter dikes/swales should be limited to a drainage area of no more than 0.8 hectare and usually work best on gently sloping terrain. Perimeter dikes may not work well on moderate slopes, and they should never be established on slopes exceeding 20 percent (UNEP, 1994).

**Regional Applicability**. Grassed swales can be applied in most regions of the country. In arid and semi-arid climates, however, the value of these practices needs to be weighed against the water needed to irrigate them.

**Ultra-Urban Areas**. Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Grassed swales are generally not well suited to ultra-urban areas because they require a relatively large area of pervious surface.

**Storm Water Hot Spots**. Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those commonly found in storm water. A typical example is a gas station or convenience store. With the exception of the dry swale design, hot spot runoff should not be directed toward grassed channels. These practices either infiltrate storm water or intersect the ground water, making use of the practices for hot spot runoff a threat to ground water quality.

**Storm Water Retrofit**. A storm water retrofit is a storm water management practice (usually structural), put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. One retrofit opportunity using grassed swales modifies existing drainage ditches. Ditches have traditionally been designed to convey storm water away from roads as quickly as possible. In some cases, it may be possible to incorporate features to enhance pollutant removal or infiltration such as check dams (for example, small dams along the ditch that trap sediment, slow runoff, and reduce the longitudinal slope). Since grassed swales cannot treat a large area, using this practice to retrofit an entire watershed would be expensive because of the number of practices needed to manage runoff from a significant amount of the watershed's land area.

**Cold Water (Trout) Streams**. Grassed channels are a good treatment option in watersheds that drain to cold water streams. These practices do not retain water for a long period of time and often induce infiltration. As a result, standing water will not typically be subjected to warming by the sun in these practices.

**Design and Installation Criteria**

Temporary swales should be designed using standard hydrologic and hydraulic calculations. Designs should be certified by a professional hydrologist, engineer, or other appropriate professional.

Perimeter dikes/swales should be established before any major soil-disturbing activity takes place. Dikes should be compacted with construction equipment to the design height plus 10 percent to allow for settlement. If they are to remain in place for longer than 10 days, they should be stabilized using vegetation, filter fabric, or other material. Diverted water should be directed to a sediment trap or other sediment treatment area (UNEP, 1994).

In addition to the broad applicability concerns described above, designers need to consider conditions at the site level. In addition, they need to incorporate design features to improve the longevity and performance of the practice while minimizing the maintenance burden.

**Siting Considerations**

In addition to considering the restrictions and adaptations of grassed swales to different regions and land uses, designers must ensure that this management practice is feasible at the site in question. Depending on the design option, grassed channels can be highly restricted practices based on site characteristics.

**Drainage Area**. Grassed swales generally should treat small drainage areas of less than 5 acres. If the practices are used to treat larger areas, the flows and volumes through the swale become too large to achieve storm water treatment through infiltration and filtration.

**Slope**. Grassed swales should be used on sites with relatively flat slopes (less than 4 percent). Runoff velocities within the channel become too high on steeper slopes. This can cause erosion and does not allow for infiltration or filtration in the swale.

**Soils /Topography**. Grassed swales can be used on most soils, with some restrictions on the most impermeable soils. In the dry swale, a fabricated soil bed replaces on-site soils to ensure that runoff is filtered as it travels through the soils of the swale.

**Ground water**. The depth to ground water depends on the type of swale used. In the dry swale and grassed channel options, designers should separate the bottom of the swale from the ground water by at least 2 feet to prevent a moist swale bottom or contamination of ground water. In the wet swale option, treatment is enhanced by a wet pool, which is maintained by intersecting the water table.

**Design Considerations**

Although the grass swale has different design variations, including the grassed channel, dry swale, and wet swale, some design considerations are common to all three. One similarity is their cross-sectional geometry. Swales should generally have a trapezoidal or parabolic cross-section with relatively flat side slopes (flatter than 3:1). Designing the channel with flat side slopes maximizes the wetted perimeter, which is the length along the edge of the swale's cross-section where runoff flowing through the swale is in contact with the vegetated sides and bottom of the swale. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage filtering and infiltration. Another advantage to flat side slopes is that runoff entering the grassed swale from the side receives some pretreatment along the side slope. The flat bottom of all three should be between 2 and 8 feet wide. The minimum width ensures an adequate filtering surface for water quality treatment, and the maximum width prevents braiding (the formation of small channels within the swale bottom).

Another similarity among all three designs is the type of pretreatment needed. A small forebay should be used at the inflow area of the swale to trap incoming sediments. A pea gravel diaphragm (a small trench filled with river run gravel) should be used to pretreat runoff entering along the sides of the swale.

Two other features designed to enhance the treatment ability of grassed swales are a flat longitudinal slope (generally between 1 and 2 percent) and a dense vegetative cover in the channel. The flat slope helps to reduce the velocity of flow in the channel. Dense vegetation also helps reduce velocities, protect the channel from erosion, and act as a filter to treat storm water runoff. During construction, it is important to stabilize the channel before the turf has been established, either with a temporary grass cover or with the use of natural or synthetic erosion control products.

In addition to treating runoff for water quality, grassed swales need to convey larger storms safely. Typical designs allow the runoff from the 2-year storm to flow through the swale without causing erosion. Swales should also have the capacity to pass larger storms (typically a 10-year storm) safely.

The length of the swale necessary to infiltrate runoff can be calculated by using a mass balance of runoff and infiltration for a triangular-shaped cross-sectional area.

### Design Variations

The following discussion identifies three different variations of open channel practices, including the grassed channel, the dry swale, and the wet swale.

**Grassed Channel**. (Discussed in more length in sub-section 5.5.1.2.1) Of the three grassed swale designs, grassed channels are the most similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes and a slower design velocity for water quality treatment of small storm events. Of all of the grassed swale options, grassed channels are the least expensive, but they also provide the least reliable pollutant removal performance. The best application of a grassed channel is as pretreatment to other storm water treatment practices.

One major difference between the grassed channel and most of the other structural practices is the method used to size the practice. Most water quality practices for storm water management are sized by volume. This method sets the volume available in the practice equal to the water quality volume, or the volume of water to be treated in the practice. The grassed channel, on the other hand, is a flow rate-based design. Based on the peak flow from the water quality storm (this varies from region to region but a typical value is the 1-inch storm), the channel should be designed so that runoff takes, on average, 10 minutes to flow from the top to the bottom of the channel. A procedure for this design can be found in *Design of Storm Water Filtering Systems* (CWP, 1996).

**Dry Swales**. Dry swales are similar in design to bioretention areas. These practices incorporate a fabricated soil bed into their design. The existing soil is replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system is used under the soil bed. This system is a gravel layer that encases a perforated pipe. Storm water treated in the soil bed flows through the bottom into the underdrain, which conveys this treated storm water to the storm drain system. Dry swales are a relatively new design, but studies of swales with a native soil similar to the man-made soil bed of dry swales suggest high pollutant removal rates.

**Wet Swales**. Wet swales intersect the ground water and behave similarly to a linear wetland cell. This design variation incorporates a shallow permanent pool and wetland vegetation to provide storm water treatment. This design also has potentially high pollutant removal. One disadvantage of the wet swale is that its use in residential or commercial settings is unpopular because the shallow standing water in the swale is sometimes viewed as a potential nuisance by property owners.

### Regional Variations

**Cold Climates**. In cold or snowy climates, swales may serve a dual purpose by acting as both a snow storage/treatment practice and a storm water management practice. This dual purpose is particularly relevant when swales are used to treat road runoff. If used for this purpose, swales should incorporate salt-tolerant vegetation, such as creeping bentgrass.

**Arid Climates**. In arid or semi-arid climates, swales should be designed with drought-tolerant vegetation, such as buffalo grass. As pointed out in the Applicability discussion, the value of vegetated practices for water quality needs to be weighed against the cost of water needed to maintain them in arid and semi-arid regions.

**Effectiveness**

Swales act to control peak discharges in two ways. First, the grass reduces runoff velocity, depending on the length and slope of the swale. Second, a portion of the storm water runoff volume passes through the swale and infiltrates into the soil. Table 5-9 summarizes grassed swale pollutant removal efficiencies.

**Table 5-9. Grassed Swale Pollutant Removal Efficiency Data**

| Grassed Swale Removal Efficiencies | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Study** | **TSS** | **TP** | **TN** | **$NO_3$** | **Metals** | **Bacteria** | **Type** |
| Goldberg, 1993 | 67.8 | 4.5 | - | 31.4 | 42–62 | -100 | Grassed channel |
| Seattle Metro and Washington Department of Ecology, 1992 | 60 | 45 | - | -25 | 2–16 | -25 | Grassed channel |
| Seattle Metro and Washington Department of Ecology, 1992 | 83 | 29 | - | -25 | 46–73 | -25 | Grassed channel |
| Wang et al., 1981 | 80 | - | - | - | 70–80 | - | Dry swale |
| Dorman et al., 1989 | 98 | 18 | - | 45 | 37–81 | - | Dry swale |
| Harper, 1988 | 87 | 83 | 84 | 80 | 88–90 | - | Dry swale |
| Kercher, Landon, and Massarelli, 1983 | 99 | 99 | 99 | 99 | 99 | - | Dry swale |
| Harper, 1988 | 81 | 17 | 40 | 52 | 37–69 | - | Wet swale |
| Koon, 1995 | 67 | 39 | - | 9 | -35 to 6 | - | Wet swale |
| Occoquan Watershed Monitoring Lab, 1983 | -100 | -100 | -100 | - | -100 | - | Drainage channel |
| Yousef et al., 1985 | - | 8 | 13 | 11 | 14–29 | - | Drainage channel |
| Occoquan Watershed Monitoring Lab, 1983 | -50 | -9.1 | -18.2 | - | -100 | - | Drainage channel |
| Yousef et al., 1985 | - | -19.5 | 8 | 2 | 41–90 | - | Drainage channel |
| Occoquan Watershed Monitoring Lab, 1983 | 31 | -23 | 36.5 | - | -100 to 33 | - | Drainage channel |
| Welborn and Veenhuis, 1987 | 0 | -25 | -25 | -25 | 0 | - | Drainage channel |
| Yu, Barnes, and Gerde, 1993 | 68 | 60 | - | - | 74 | - | Drainage channel |
| Dorman et al., 1989 | 65 | 41 | - | 11 | 14–55 | - | Drainage channel |
| Pitt and McLean, 1986 | 0 | - | 0 | - | 0 | 0 | Drainage channel |
| Oakland, 1983 | 33 | -25 | - | - | 20–58 | 0 | Drainage channel |
| Dorman et al., 1989 | -85 | 12 | - | -100 | 14–88 | - | Drainage channel |

## Limitations

Common problems associated with swales include excessive erosion along unlined channels (usually because of excessive grade), erosion or sedimentation at the outlet point, or overtopping of the dike at low points (UNEP, 1994).

Additional limitations of the grass swale include the following:

- Grassed swales cannot treat a very large drainage area.

- Swales do not appear to be effective at reducing bacteria.
- Wet swales may become a nuisance because of mosquito breeding.
- If designed improperly (for example, improper slope), grassed channels will have very little pollutant removal.
- A thick vegetative cover is needed for these practices to function properly.

**Maintenance**

As with any BMP, swales must be maintained to continue to effectively remove pollutants. Maintenance may include occasional mowing, fertilizing, and liming. In addition, any areas that become damaged by erosion should be immediately repaired and replanted. The swales should be protected from concentrated flows and be checked periodically for downstream obstructions.

**Cost**

To produce a conceptual cost approximation, grassed channel construction costs can be developed using unit cost values. Shallow trenching (1 to 4 feet deep) with a backhoe in areas not requiring dewatering can be performed for $4 to $5 per cubic yard of removed material (R. S. Means, 2000). Assuming no disposal costs (i.e., excavated material is placed on either side of the trench), only the cost of fine grading, soil treatment, and grassing (approximately $2 per square yard) should be added to the trenching cost to approximate the total construction cost. Site-specific hydrologic analysis of the construction site is necessary to estimate the channel conveyance requirement and the desired retention time in the swale. It is not unusual to have flows on the order of 2 to 4 cfs per acre served.

For a design channel velocity of 1 foot per second, the resulting range in the channel cross-section area can be as low as 2 but as high as 4 square feet per acre drained. If the average channel flow depth is 1 foot, then the low estimate for grassed channel installation is $0.74 per square foot of channel bottom per acre served per foot of channel length. The high estimate is $1.48 per square foot of channel bottom per acre served per foot of channel length.

Table 5-10 summarizes additional costs of grass swales.

**Table 5-10. Average Annual Operation and Maintenance Costs for a Grass Swale**

| Component | Estimated Unit Cost ($) | $ for Swale Size: 0.5 m Deep X 0.3 m Bottom Width X 3 m Top Width | $ for Swale Size: 1 m Deep X 1 m Bottom Width X 7 m Top Width | Comments |
|---|---|---|---|---|
| Mowing | 0.89/100 $m^2$ | 145.0 | 241.0 | Mow 2-3 times per year |
| General grass care | 8.8/100 $m^2$ | 162.98 | 274.0 | Grass maintenance area is (top width + 3 m) x length |
| Debris/litter removal | 0.51/$m^2$ | 93.0 | 93.0 | |
| Reseeding/ fertilization | 0.35/$m^2$ | 5.9 | 10.37 | Area revegetated is 1% of maintenance area per year |
| Inspection and general administration | 0.74/$m^2$ | 231.0 | 231.0 | Inspection once per year |
| TOTAL | | 638.0 | 850.0 | |

Source: Ellis, 1998.

#### 5.1.5.2.3 Temporary Storm Drain Diversion

**General Description**

A temporary storm drain diversion is a pipe that reroutes an existing drainage system to discharge flow into a sediment trap or basin. This practice reduces the amount of sediment-laden runoff from construction sites that enters waterbodies without treatment. Temporary storm drain diversions can be used when a permanent storm water drainage system has not yet been installed. It should be recognized that diversion channels can also be installed but are not considered in the following discussion.

**Applicability**

A temporary storm drain diversion should be used to temporarily redirect discharge to a permanent outfall and should remain in place until the area draining to the storm sewer is no longer disturbed. Temporary storm drain diversions can also be combined with other structures and used as a sediment-trapping device when the completion of a permanent outfall has been delayed; alternatively, a sediment trap can be placed below a permanent outfall to remove sediment before the final flow discharge.

**Design and Installation Criteria**

Since the diversion is only temporary, the layout of piping and the overall impact of the diversion's installation on post-construction drainage patterns must be considered. Once construction is completed, the temporary diversion should be moved to restore the original system. The following activities should be done at this time:

- The storm drain should be flushed before the sediment trap is removed.
- The outfall should be stabilized.
- Graded areas should be restored.
- State or local requirements should be checked for more detailed requirements and an appropriate professional should certify that the design meets local hydrologic and hydraulic requirements.

**Effectiveness**

If installed properly to capture the bulk of runoff from a construction site, temporary storm drain diversions can be effective in reducing the discharge of sediment-laden, untreated water to waterbodies. When used in combination with other erosion and sediment control practices such as minimized clearing or vegetative and chemical stabilization, the level of pollution from a construction site can be substantially reduced or eliminated.

**Limitations**

Installation of a temporary storm drain diversion may result in the disturbance of existing storm drainage patterns. Care must be taken to ensure that the original system is properly restored once the temporary system is removed. The most common source of problems is excessive velocity at the outlet. Installation of an outlet stabilization structure is typically required and may be constructed of riprap, reinforced concrete, geotextile linings, or a combination.

**Maintenance**

Once installed, temporary storm drain diversions require very little maintenance. Frequent inspection and maintenance of temporary storm drain systems, especially after large storms, should ensure that pipe clogging does not occur and that runoff from the site is being successfully diverted. After removal of the temporary diversion, the permanent storm drain system should be carefully inspected to ensure that drainage patterns have not been altered by the temporary system.

**Cost**

Depending on the size of the construction site, a temporary storm drain diversion can be costly. Costs include those associated with materials needed to construct the diversion and sediment trap or basin (mainly piping, concrete, and gravel), and also labor costs for installation and removal of the system, all of which may involve excavation, regrading, and inspections. Based on the variety of conditions that can affect storm drain diversion designs, typical costs per installation are not presented here. However, site-specific cost estimates can be produced using unit cost values along with site-specific quantity estimates. R. S. Means (2000) indicates a range of pipe costs for surface placement, between $5.00 per linear foot for 4" diameter PVC piping, and $9.20 per linear foot for 10" diameter PVC piping. On construction sites, temporary inlets and outlets are usually formed by small rock-lined depressions. Assuming 4 cubic yards of crushed rock (1.5" mean diameter) per opening, an inlet and outlet combine to add approximately $200 per pipe installation, based on $25 per cubic yard of stone (R. S. Means, 2000).

### 5.1.5.2.4 Pipe Slope Drain

**General Description**

Pipe slope drains are used to reduce the risk of erosion on slopes by discharging runoff to stabilized areas. Consisting of a metal or plastic flexible pipe if temporary, or pipes or paved chutes if permanent, these drains carry surface runoff from the top to the bottom of a slope that has already been damaged by erosion or is at high risk for erosion. These drains are also used to drain saturated slopes that have the potential for soil slides.

**Applicability**

Temporary slope drains can be used on most disturbed slopes to eliminate gully erosion problems resulting from concentrated flows discharged at a diversion outlet. Slope drains should be used as a temporary measure for as long as the drainage area remains disturbed. They will need to be moved once construction is complete and a permanent storm drainage system is established. Appropriate restoration measures will then need to be taken, such as adjusting grades and flushing sediment from the pipe before it is removed (UNEP, 1994).

**Design and Installation Criteria**

Pipe slope drains can be placed directly on the ground or buried under the surface. The inlet should be located at the top of the slope and should be fitted with an apron, attached with a watertight connection. Filter cloth should be placed under the inlet to prevent erosion. Flexible pipes, which are positioned on top of the ground, should be securely anchored with grommets placed 10 feet on center. The outlet at the bottom of the slope should also be stabilized with riprap. The riprap should be placed along the bottom of a swale that leads to a sediment-trapping structure or another stabilized structure.

Slope drain pipe sizes are based on drainage area and the size of the design storm. Pipes should be connected to a diversion ridge at the top of the slope by covering it with compacted fill material where it passes through the ridge. Discharge from a slope drain should be to a sediment trap, sediment basin, or other stabilized outlet (UNEP, 1994).

Pipe slope drains should be installed perpendicular to the contour down the slope, and the design should be able to handle the peak runoff for the 10-year storm. Recommendations of slope drain diameter are summarized in Table 5-11 (NAHB, n.d).

**Table 5-11. Recommended Pipe/Tubing Sizes for Slope Drains**

| Maximum Drainage Area (acres) | Pipe/Tubing Diameter[a] (inches) | Pipe/Tubing Diameter[b] (inches) | Pipe/Tubing Diameter[c] (inches) |
|---|---|---|---|
| 0-0.5 | | | |
| 0.5 | 12 | 12 | 8 |
| 0.75 | | | 10 |
| 1.0 | | | 12 |
| 1.5 | 18 | 18 | Individually designed |
| 2.5 | 21 | | |
| 3.5 | 24 | 24 | |
| 5.0 | 30 | | |

[a] UNEP, 1994.
[b] USDOT, 1995.
[c] IDNR, 1992.

Recently graded slopes that do not have permanent drainage measures installed should have a temporary slope drain and a temporary diversion installed. A temporary slope drain used in conjunction with a diversion conveys storm water flows and reduces erosion until permanent drainage structures are installed.

The following are design recommendations for temporary slope drains:

- The drain should consist of heavy-duty material manufactured for the purpose and have grommets for anchoring at a spacing of 10 feet or less.

- Minimum slope drain diameters should be observed for varying drainage areas.

- The entrance to the pipe should consist of a standard flare end section of corrugated metal. The corrugated metal pipe should have watertight joints at the ends. The rest of the pipe is typically corrugated plastic or flexible tubing, although for flatter, shorter slopes, a polyethylene-lined channel is sometimes used.

- The height of the diversion at the pipe should be the diameter of the pipe plus 0.5 foot.

- The outlet should be located at a reinforced or erosion-resistant location.

Temporary slope drains should be designed to adequately convey runoff for a desired frequency storm, typically either 2 years or 10 years depending on local regulations. Both the size and the spacing can be determined based on the contributing drainage area. Drains are spaced at intervals corresponding to the specified drainage areas. For larger drainage areas and critical locations, the drains should be sized on an individual basis (USDOT, 1995).

Slope drains should be constructed in conjunction with diversion berms such that the berms are not overtopped. At the pipe inlet, the top of the berm should be a minimum of 300 mm (11.81 inches) higher than the top of the pipe. The entrance should be constructed of a standard flared end section or a Tee section if designed properly. The entrance should be placed in a sump that is depressed 150 mm (5.90 inches) (USDOT, 1995).

The outlet of the slope drain must be protected with a riprap apron. If the slope drain is draining a disturbed area and sufficient right-of-way is available, the drain may empty into a sediment trap (USDOT, 1995). Table 5-12 summarizes slope drain characteristics.

**Table 5-12. Slope Drain Characteristics**

| | |
|---|---|
| Capacity | 2-yr frequency, 24-hr-duration storm event |
| Material | Strong, flexible pipe, such as heavy duty, nonperforated, corrugated plastic |
| Inlet section | Standard "T" or "L" flared-end section with metal toe plate |
| Connection to ridge at top of slope | Compacted fill over pipe with minimum dimensions, 1.5 ft depth, 4 ft top width, and 6 in higher than ridge |
| Outlet | Pipe extends beyond toe of slope and discharges into a sediment trap or basin unless contributing drainage area is stable |

Source: IDNR, 1992.

**Effectiveness**

There is currently no information on the effectiveness of pipe slope drains.

**Limitations**

The area drained by a temporary slope drain should not exceed 5 acres. Physical obstructions substantially reduce the effectiveness of the drain. A common slope drain problem is overtopping of the inlet due to an undersized or blocked pipe, or erosion at the outlet point due to insufficient protection (UNEP, 1994). Other concerns are failures from overtopping because of inadequate pipe inlet capacity and reduced diversion channel capacity and ridge height.

Solutions to common problems include the following (IDNR, 1992):

- Washout - A washout along a pipe due to seepage and piping may be caused by inadequate compaction, insufficient fill, or installation that may be too close to the edge of the slope.

- Overtopping caused by undersized or blocked pipe - The drainage area may be too large.

- Overtopping caused by improper grade of channel and ridge - A positive grade should be maintained.

- Overtopping caused by poor entrance conditions and trash buildup at the pipe inlet - Deepen and widen the channel at the pipe entrance and frequently inspect and clear the inlet.

- Erosion at outlet - The pipe should be extended to a stable grade or an outlet stabilization structure is needed.

- Displacement or separation of pipe - The pipe should be tied down and the joints secured.

**Maintenance**

Pipe slope drains must be inspected after each significant runoff event for evidence of erosion and uncontrolled runoff. Any repairs to the drain should be made immediately. Significant amounts of sediment trapped at the outfall should also be removed in a timely manner and disposed of properly (NAHB, No Date).

The following actions should be taken to properly maintain a pipe slope drain (IDNR, 1992):

- Inspect slope drains and supporting diversions once a week and after every storm event.

- Check the inlet for sediment or trash accumulation; clear and restore to proper entrance condition.

- Check the fill over the pipe for settlement, cracking, or piping holes; repair immediately.

- Check for holes where the pipe emerges from the dike; repair immediately.

- Check the conduit for evidence of leaks or inadequate anchoring; repair immediately.

- Check the outlet for erosion or sedimentation; clean and repair, or extend if necessary.

- Once slopes have been stabilized, remove the temporary diversions and slope drains, and stabilize all disturbed areas.

**Cost**

The cost of pipe slope drains and their installation varies with the design and materials used. Site-specific cost estimates can be produced using unit cost values with site-specific quantity estimates. R. S. Means (2000) indicates a range of pipe costs for surface placement between $5.00 per linear foot for 4-inch diameter PVC piping, and $9.20 per linear foot for 10-inch diameter PVC piping. On construction sites, temporary inlets and outlets are usually formed by small rock-lined depressions. Assuming 4 cubic yards of crushed rock (1.5-inch mean diameter) per opening, an inlet and outlet together add approximately $200 per pipe installation, based on $25 per cubic yard of stone (R. S. Means, 2000).

### 5.1.5.2.5 Stone Check Dam

**General Description**

A check dam is a small temporary barrier constructed across a drainage channel or swale to reduce the velocity of the flow. By reducing the flow velocity, the erosion potential is reduced, detention times are lengthened, and more sediments are able to settle out of the water column. Check dams can be constructed of stone, gabions, treated lumber, or logs (NAHB, No Date).

Check dams are inexpensive and easy to install. They may be used permanently to settle sediment, reduce the velocity of runoff, and provide aeration. However, the use of check dams in a channel should not be a substitute for the use of other sediment-trapping and erosion control measures. As with most other temporary structures, check dams are most effective when used in combination with other storm water and erosion and sediment control measures.

**Applicability**

Check dams are commonly used (1) in channels that are degrading but where permanent stabilization is impractical because of their short period of usefulness and (2) in eroding channels where construction delays or weather conditions prevent timely installation of erosion-resistant linings (IDNR, 1992).

Check dams are also useful in steeply sloped swales, in small channels, in swales where adequate vegetative protection cannot be established, or in swales or channels that will be used for a short period of time where it is not practical to line the channel or implement other flow control practices (USEPA, 1993). In addition, check dams are appropriate where temporary seeding has been recently implemented but has not had time to fully develop and take root. The contributing drainage area should range from 2 to 10 acres. Check dams should be used only in small open channels that will not be overtopped by flow once the dams are built and should not be built in stream channels, either intermittent or perennial (UNEP, 1994).

### Design and Installation Criteria

Check dams can be constructed from a number of different materials. Most commonly, they are made of rock, logs, sandbags, or straw bales. Rock or stone is often preferred because of its cost-effectiveness and longevity. Logs and straw bales will decay with time and are not recommended as they may cause waterway blockage if they fail. When using rock or stone, the material diameter should be 2 to 15 inches. The stones should be extended 18 inches beyond the banks, and the side slopes should be 2:1 or flatter. Lining the upstream side of the dam with a foot of 1- to 2-inch gravel may improve the efficiency of the dam (NAHB, No Date). Logs should have a diameter of 6 to 8 inches. Regardless of the material used, careful construction of a check dam is necessary to ensure its effectiveness.

The distance between rock check dams will vary depending on the slope of the ditch, with closer spacing when the slope is steeper. The size of stone used in the check dam should also vary with the expected design velocity and discharge. As velocity and discharge increase, the rock size should also increase. For most rock check dams, 3 inches to 12 inches is a suitable stone size. To improve the sediment-trapping efficiency of check dams, a filter stone can be applied to the upstream face. A well-graded coarse aggregate that is less than 1 inch in size can be used as a filter stone.

All check dams should have a maximum height of 3 feet. The center of the dam should be at least 6 inches lower than the edges. This design creates a weir effect that helps to channel flows away from the banks and prevent further erosion. Additional stability can be achieved by implanting the dam material approximately 6 inches into the sides and bottom of the channel (VDCR, 1995).

When installing more than one check dam in a channel, outlet stabilization measures should be installed below the final dam in the series. Because this area is likely to be vulnerable to further erosion, riprap or some other stabilization measure is highly recommended.

### Effectiveness

Field experience has shown that rock check dams are more effective than silt fences or straw bales to stabilize wet-weather ditches (VDCR, 1995). Straw bales have been shown to have very low trapping efficiencies and should not be used for check dams. For long channels, check dams are most effective when used in a series, creating multiple barriers to sediment-laden runoff.

### Limitations

Check dams should not be used in perennial streams unless approved by an appropriate regulatory agency (USEPA, 1992; VDCR, 1995). Because the primary function of check dams is to slow runoff in a channel, they should not be used as a stand-alone substitute for other sediment-trapping devices. Also, leaves have been shown to be a significant problem, as they clog check dams; therefore, increased inspection and maintenance might be necessary in the fall. Common problems with check dams include channel bypass and severe erosion when overtopped and ineffectiveness due to accumulated sediment and debris. When designing check dams, the fact that they will reduce the capacity of a channel to transmit storm water runoff and thus will need to be sized appropriately should be taken into account (UNEP, 1994). The check dam may also kill grass linings in the channel if the water level remains high after it rains or if there is significant sedimentation. In addition, a check dam may reduce the hydraulic capacity of the channel and create turbulence, which erodes the channel banks (NAHB, No Date).

**Maintenance**

Check dams should be inspected periodically to ensure that they have not been repositioned as a result of storm water flow. In addition, the center of a check dam should always be lower than its edges. Additional stone may have to be added to maintain the correct height. Sediment should not be allowed to accumulate to more than half the original dam height. Any required maintenance should be performed immediately. When check dams are removed, care must be taken to remove all dam materials to ensure proper flow within the channel. The channel should subsequently be seeded for stabilization (NAHB, No Date).

**Cost**

The cost of check dams varies based on the material used for construction and the width of the channel to be dammed. In general, it is estimated that check dams constructed of rock cost about $100 per dam (USEPA, 1992). Brown and Schueler (1997) estimated that a rock check dam would cost approximately $62 per installation, including the cost for filter fabric bedding. Other materials, such as logs and sandbags, may be a less expensive alternative, but they might require higher maintenance costs.

### 5.1.5.2.6 Lined Waterways

**General Description**

Lined channels convey storm water runoff through a stable conduit. Vegetation lining the channel reduces the flow velocity of concentrated runoff. Lined channels usually are not designed to control peak runoff loads by themselves and are often used in combination with other BMPs such as subsurface drains and riprap stabilization. Where moderately steep slopes require drainage, lined channels can include excavated depressions or check dams to enhance runoff storage, decrease flow rates, and enhance pollutant removal. Peak discharges can be reduced through temporary detention in the channel. Pollutants can be removed from storm water by filtration through vegetation, by deposition, or in some cases by infiltration of soluble nutrients into the soil. The degree of pollutant removal in a channel depends on the residence time of the water in the channel and the amount of contact with vegetation and the soil surface, but pollutant removal is not generally the major design criterion.

Often construction increases the velocity and volume of runoff, which causes erosion in newly constructed or existing urban runoff conveyance channels. If the runoff during or after construction will cause erosion in a channel, the channel should be lined or flow control practices instituted. The first choice of lining should be grass or sod because this reduces runoff velocity and provides water quality benefits through filtration and infiltration. If the velocity in the channel would erode the grass or sod, riprap, concrete, or gabions can be used (USEPA, 2000). Geotextile materials can be used in conjunction with either grass or riprap linings to provide additional protection at the soil-lining interface.

**Applicability**

Lined channels typically are used in residential developments, along highway medians, or as an alternative to curb and gutter systems. Grass-lined channels should be used to convey runoff only where slopes are 5 percent or less. These channels require periodic mowing, occasional spot-seeding, and weed control to ensure adequate grass cover (UNEP, 1994).

Lined channels should be used in areas where erosion-resistant conveyances are needed, such as in areas with highly erodible soils and slopes of less than 5 percent. They should be installed only where space is available for a relatively large cross-section. Grassed channels have a limited ability to control runoff from large storms and should be used with the recommended allowable velocities for the specific soil types and vegetative cover.

**Design and Installation Criteria**

The design of a lined waterway requires proper determination of the channel dimensions. It must ensure that (1) the velocity of the flowing water will not wash out the waterway and that (2) the capacity of the waterway is sufficient to carry the surface flow from the watershed without overtopping.

**Vegetation-Lined Channels.** Grass-lined channels have been previously discussed in detail and are only summarized in this section. The allowable velocity of water in the waterway depends upon the type, condition, and density of the vegetation, as well as the erosive characteristics of the soil. Uniformity of vegetative cover is important because the stability of the most sparsely covered area determines the stability of the channel. Grasses are a better vegetative cover than legumes because grasses resist water velocity more effectively.

Vegetative-lined channels may have triangular, parabolic, or trapezoidal cross-sections. Side slopes should not exceed 3:1 to facilitate the establishment, maintenance, and mowing of vegetation. A dense cover of hardy, erosion-resistant grass should be established as soon as possible following grading. This may necessitate the use of straw mulch and the installation of protective netting until the grass becomes established. If the intent is to create opportunities for runoff to infiltrate into the soil, the channel gradient should be kept near zero, the channel bottom must be well above the seasonal water table, and the underlying soils should be relatively permeable (generally, with an infiltration rate greater than 2 centimeters [0.78 inches] per hour).

**Rock-Lined Channels.** Riprap-lined channels may be installed on somewhat steeper slopes than grass-lined channels. They require a foundation of filter fabric or gravel under the riprap. Generally, side slopes should not exceed 2:1, and riprap thickness should be 1.5 times the maximum stone diameter. Riprap should form a dense, uniform, well-graded mass (UNEP, 1994).

Lined channels should be sited in accordance with the natural drainage system and should not cross ridges. The channel design should not have sharp curves or significant changes in slope. Channels should not receive direct sedimentation from disturbed areas and should be established only on the perimeter of a construction site to convey relatively clean storm water runoff. They should also be separated from disturbed areas by a vegetated buffer or other BMP to reduce sediment loads.

Basic design recommendations for lined channels include the following:

- Construction and vegetation of the channel should occur before grading and paving activities begin.
- Design velocities should be less than 5 feet per second.
- Geotextiles can be used to stabilize vegetation until it is fully established.
- Covering the bare soil with sod or geotextiles can provide reinforced storm water conveyance immediately.
- Triangular-shaped channels should be used with low velocities and small quantities of runoff; parabolic grass channels are used for larger flows and where space is available; trapezoidal channels are used with large flows of low velocity (low slope).
- Outlet stabilization structures might be needed if the runoff volume or velocity has the potential to exceed the capacity of the receiving area.
- Channels should be designed to convey runoff from a 10-year storm without erosion.
- The sides of the channel should be sloped less than 3:1, with V-shaped channels along roads sloped 6:1 or less for safety.
- All trees, bushes, stumps, and other debris should be removed during construction.

**Effectiveness**

Lined channels can effectively transport storm water from construction areas if they are designed for expected flow volumes and velocities and if they do not receive sediment directly from disturbed areas.

**Limitations**

Lined channels, if improperly installed, can alter the natural flow of surface water and have adverse impacts on downstream waters. Additionally, if the design capacity is exceeded by a large storm event, the vegetation might not be sufficient to prevent erosion and the channel might be destroyed. Clogging with sediment and debris reduces the effectiveness of grass-lined channels for storm water conveyance.

Common problems in lined channels include erosion of the channel before vegetation is fully established and gullying or head cutting in the channel if the grade is too steep. In addition, trees and brush tend to invade lined channels, causing maintenance problems.

Riprap-lined channels can be designed to safely convey greater runoff volumes on steeper slopes. However, they should generally be avoided on slopes exceeding 10 percent because stone displacement, erosion of the foundation, or channel overflow and erosion resulting from a channel that is too small can occur. Thus, channels established on slopes greater than 10 percent will usually require protection with rock gabions, concrete, or other highly stable and protective surfaces (UNEP, 1994).

**Maintenance**

Maintenance requirements for lined channels are relatively minimal. During the vegetation establishment period, the channels should be inspected after every rainfall. Other maintenance activities that should be carried out after vegetation is established are mowing, litter removal, and spot vegetation repair. The most important objective in the maintenance of lined channels is maintaining a dense and vigorous growth of turf. Periodic cleaning of vegetation and soil buildup in curb cuts is required so that water flow into the channel is unobstructed. During the growing season, channel grass should be cut no shorter than the level of design flow, and the cuttings should be removed promptly.

**Cost**

Costs of grassed channels range according to depth, with a 1.5-foot-deep, 10-foot-wide grassed channel estimated at $6,395 to $17,075 per trench, while a 3.0-foot-deep, 21-foot-wide grassed channel is estimated at $12,909 to $33,404 per trench (SWRPC, 1991).

Readers are also referred to the discussion of costs for grass-lined channels, which contains many of the design and cost elements required for installing lined waterways. Designers have a range of options for lining new channels. Geosynthetic turf reinforcement mattings (TRMs) can be used for immediate erosion protection in channels exposed to runoff flows. The Erosion Control Technology Council (a geotextile industry support association) suggests TRMs cost approximately $7.00 per square yard (installed) for channel protection (ECTC, 2002a). R. S. Means indicates machine-placed riprap costs of approximately $40 per cubic yard. The riprap maximum size is typically between 6 and 12 inches, depending on the channel design velocity. A cubic yard of riprap will cover between 36 and 18 square feet of channel bed for these riprap sizes (assuming depth of riprap is 1.5 times the maximum size). These estimates suggest that riprap lining will be between $10 and $20 per square foot of channel (costs include materials, labor, and equipment, with overhead and profit).

### 5.1.5.3 Sediment Trapping Devices

The devices listed under this group of BMPs trap sediment primarily through impounding water and allowing for settling to occur (Haan et al., 1994). Silt fence, super silt fence, straw bale dikes, sediment traps, and sediment basins all control flow through a porous flow control system such as filter fabric or straw bales or they use a dam to impound water with a pipe, open channel, or rock fill outlet. The filtering capacity of silt fence (filter fabric) contributes only a small amount of trapping, but serves to make the fence less porous and hence increases ponding. For steady-state flows, the trapping that occurs behind the flow control device can be shown to be directly proportional to the surface area and indirectly proportional to flow through the system (Haan et al., 1994). The ratio of the surface area to flow is known as the overflow rate, and trapping in such systems is predicted by the ratio of overflow rate to particle settling velocity. Although flows in nature are inherently non-steady state and more complex than steady-state systems, studies have shown that the best predictor of trapping in such systems is still the ratio of settling velocity to overflow rate (Hayes et al., 1984). In the case of non-steady state, the overflow rate is best defined by the ratio of peak discharge to surface area (Hayes et al., 1984; McBurnie et al., 1990).

The amount of trapping in these structures depends on the size of the structure, flow rates into the system, hydraulics of the flow control system, the size distribution of the sediment flowing into the structure, and the chemistry of the sediment-water system (Haan et al., 1994). Trapping can be enhanced by chemical treatment of flows into the structure, but the impacts have not been widely defined for varying mineralogy and chemistry of the sediment-water system (Haan et al., 1994; Tapp and Barfield, 1986). Recent studies have been conducted on the application of polyacrylamides (PAM) to disturbed areas for enhancing settling (Benik et al., 1998; Masters et al., 2000; Roa-Espinosa et al., 2000), but results have not been definitive. No known studies have evaluated the impacts of PAM application to disturbed areas on settling in sediment trapping devices.

Sediment flowing into sediment trapping devices is composed of primary particles and aggregated particles. Aggregates are formed when clays, silts, and sands are cemented together to form larger particles that have settling velocities far greater than those of any individual particles alone, although the degree of aggregation depends on the amount of cementing material present (typically clays and organic matter). Since the aggregates have higher settling velocities than primary particles, the degree of aggregation that is present has a large impact on the trapping that occurs. Procedures are available to measure the combined size distribution of aggregate and primary particle size distribution (Barfield et al., 1979; Haan et al., 1994). Procedures are also available to predict particle size distributions of aggregates and primary particles (Foster et al., 1985), but have not been found to be very accurate for subsoils exposed during construction in at least one study (Barfield et al., 1983).

In the absence of chemical treatment, the sediment that can be captured in sediment trapping devices is typically the larger settleable solids. To trap the smaller size clay particles, structures with surface areas larger than the construction site itself would have to built in many cases (Barfield, 2000). Chemical treatment can be used to reduce the size captured, but it has not been adopted on a wide scale because of the cost and complexity of the operation (Tapp et al., 1981).

Sediment trapping devices also provide some storm water detention by virtue of detaining flows long enough to allow sediment to settle out and be deposited. However, to operate as a storm water detention structure, the design should include adequate volume for detention.

Virtually all of the available information on sediment trapping structures, both theoretical and experimental, is on impacts to receiving waters and not downstream effects. In a very limited analysis, Barfield (2000) combined the SEDIMOT II computer model together with the FLUVIAL model to theoretically evaluate the impact of sediment trapping structures on downstream geomorphology in a Puerto Rican watershed.

#### 5.1.5.3.1 Silt Fence

**General Description**

Silt fences are used as temporary sediment barriers consisting of filter fabric anchored across and supported by posts. Their purpose is to retain sediment from small disturbed areas by reducing the velocity of sediment-laden runoff and promoting sediment deposition (Smolen et al., 1988). Silt fences capture sediment by ponding water and allowing for deposition, not by filtration. Silt fence fabric first screens silt and sand from runoff, resulting in clogging of the lower part of the fence. The pooling water allows sediments to settle out of the runoff. Silt fences work best in conjunction with temporary basins, traps, or diversions.

**Applicability**

Silt fences are generally placed at the toe of fills, along the edge of waterways, and along the site perimeter. The fences should not be used in drainage areas with concentrated and high flows, in large drainage areas, or in ditches and swales where concentrated flow is present.

The drainage area for the fence should be selected based on design storms and local hydrologic conditions so that the silt fence is not expected to overtop. A typical design calls for no greater than ¼ acre of drainage area per 100 feet of fence, but this is highly variable depending on climate. The fence should be stable enough to withstand runoff from a 10-year peak storm. Table 5-13 lists the maximum slope length specified by the USDOT. These slope lengths should be based on sediment load and flow rates. This would mean that the values given below should be adjusted for climatic conditions instead of "one size fits all" to ensure maximum effectiveness.

**Table 5-13. Maximum Slope Lengths for Silt Fences**

| Slope (%) | 18- inch (460 mm) Fence | 30- inch (760 mm) Fence |
|---|---|---|
| ≤2 | 250 ft (75 m) | 500 ft (150 m) |
| 5 | 100 ft (30m) | 250 ft (75 m) |
| 10 | 50 ft (15 m) | 150 ft (45 m) |
| 20 | 25 ft (8 m) | 70 ft (21 m) |
| 25 | 6 m (20 ft) | 55 ft (17 m) |
| 30 | 15 ft (5 m) | 45 ft (14 m) |
| 35 | 15 ft (5 m) | 40 ft (12 m) |
| 40 | 15 ft (5 m) | 35 ft (10 m) |
| 45 | 10 ft (3 m) | 30 ft (9 m) |
| 50 | 10 ft (3m) | 25 ft (8m) |

Source: USDOT, 1995.

Typical standards and specifications call for the silt fence to be located on fairly level ground and follow the land contour. However, field evaluations by Barfield and Hayes (1992, 1999) in South Carolina and Kentucky indicate that installations on the contour as well as along a slope have problems with undercutting. In either case, the installations are such that a slight slope may occur along the fence in spite of the best installation practices. Runoff can move down the contour until a weak spot occurs in the buried toe and undercuts the fence. Alternatively, flow may move to a low spot where it accumulates and causes an overtopping. In either case, trapping by the silt fence is essentially zero, and flows will then have been concentrated, causing downslope erosion.

**Design and Installation Criteria**

Design criteria are of two types:

- Hydrologic design for a required trapping of sediment and flow rate to pass the design storm.
- Selection of appropriate installation criteria such that the silt fence will perform as designed.

*Hydrologic Design*

The fence should be designed to pass the design storm without causing damage while trapping the required amount of sediment. It is necessary to use either a database or some type of model to develop the appropriate hydrologic design. Efforts to model the sediment trapping that occurs through the use of a silt fence have resulted in models that predict the settling in the ponded area upstream from the fence (Barfield et al., 1996; Lindley et al., 1998). The results from model simulations show that trapping depends primarily on the surface area of the impounded water and the flow rate through the filter. The models utilize a clear water flow rate, typically specified by the manufacturer, to predict discharge. However, numerous studies have shown that sediment laden flows cause clogging of the geotextiles used to construct the fence, dependent on the opening size and size of the sediment (Britton et al., 2001; Wyant, 1980; Barrett et al., 1995; Fisher and Jarret, 1984). Thus, results from model studies to date are suspect and need to be modified to account for the impacts of clogging on flow rate. Barfield et al., (2001) developed a model of flow rate using conditional probability concepts, but the results have not been experimentally verified.

Design aids have been developed for silt fence, using simulations from the SEDIMOT III model (Hayes and Barfield, 1995). In the model, predictions are made about trapping efficiency using the ratio of settling velocity for the $d_{15}$[4] of the eroded sediment, divided by the ratio of discharge to ponded surface area. The design aids yield conservative estimates as compared to the SEDIMOT III model, but the database used for generating the design aid is based on the assumption that clogging does not impact flow rates. The discussion above shows that assumption to be erroneous.

SEDCAD takes the approach of using a slurry flow rate, not a clean water flow rate, when it simulates fence effectiveness, reporting slurry rates rangING between 0.1 and 15 gpm/sq. ft. Based on this discussion, one can conclude that it is difficult to predict with accuracy the trapping efficiency of silt fence under a given set of conditions. In addition, the quality of installation and maintenance are important to the long-term performance of the fence. The best available estimate of sediment trapping obtained from modeling of hydrologic events should be applied with care in any site design problem.

*Installation Criteria*

General installation criteria for the silt fence should incorporate the following factors:

- The fabric must have sufficient strength to counter forces created by contained water and sediment (Sprague, 1999).
- The posts must have sufficient strength to counter the forces transferred to them by the fabric (Sprague, 1999).
- The fabric must be installed to ensure that the loads are all adequately transferred through the fabric to the posts or the ground without overstressing (Sprague, 1999).
- The fence must be designed based on site-specific hydrologic and soil conditions such that it will not overtop during design events.
- The fence must be installed (anchored) with a buried toe of sufficient depth so that it does not become detached from the soil surface.

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[4]$d_{15}$:15 percent by weight of suspended solids are smaller than those that are trapped by this device; Similarly $d_{50}$ indicates that 50 percent by weight of suspended solids are smaller than those trapped.

- In general, the fence requires a metal wire backing to provide sufficient strength to prevent failure from the weight of trapped sediment and to prevent the toe of the fabric from being removed from the ground.

- Maximum drainage area behind the fence should be determined based on the local rainfall and the infiltration characteristics of the soil and cover.

Silt fence material is typically synthetic filter fabric or a pervious sheet of polypropylene, nylon, polyester, or polyethylene yarn. The fabric should have ultraviolet ray inhibitors and stabilizers to provide for a minimum useful construction life of 6 months or the duration of construction, whichever is greater. The height of the fence fabric should not exceed 3 feet. If standard strength filter fabric is used, it should be reinforced with a wire fence, extending down into the trench that buries the toe. The wire should be of sufficient strength to support the weight of the deposited sediment and water. In general, a minimum 14 gauge and a maximum mesh spacing of 6 inches is called for (Smolen et al., 1988). Typical requirements for the silt fence physical properties, as specified in selected local BMP standards and specifications, are included in Table 5-14.

**Table 5-14. Typical Requirements for Silt Fence Fabric**

| Physical Property | Requirements | |
|---|---|---|
| | **Woven Fabric** | **Non-Woven Fabric** |
| Filtering Efficiency | 85% | 85% |
| Tensile Strength at 20% (maximum) Elongation | Standard Strength —30 pound/linear inch<br>Extra Strength —50 pound/linear inch | Standard Strength —50 pound/linear inch<br>Extra Strength —70 pound/linear inch |
| Slurry Flow Rate | 0.3 gallon/square feet/minute | 4.5 gallon/square feet/minute |
| Water Flow Rate | 15 gallon/square feet/minute | 220 gallon/square feet/minute |
| UV Resistance | 70% | 85% |

Source: NCDNR, 1988; IDNR 1992.

It should be pointed out that these numbers, particularly the flow rates, could vary widely depending on the local soil condition due to possible clogging of the filter material.

Material for the posts used to anchor the filter fabric can be constructed of either wood or steel. Wooden stakes should be buried at a depth sufficient to keep the fence, when loaded with sediment and water, from falling over. The depth of burial should depend on post diameter and soil strength characteristics when saturated. Many standards and specifications set a minimum post length of 5 feet with 4-inch diameter for posts composed of softwood (e.g, pine) and 2-inch diameter for posts composed of hardwood (e.g., oak) (Smolen et al., 1988). Steel posts should also be designed based on local wet soil strength characteristics. Some standards and specifications for these posts set a minimum weight of 1.33 pounds per linear feet with a minimum length of 4 feet. Steel posts should also have projections to adhere filter fabric to the post (Smolen et al., 1988).

A silt fence should be erected in a continuous fashion from a single roll of fabric so as to eliminate unwanted gaps in the fence. If a continuous roll of fabric is not available, the fabric should overlap from both directions only at posts with a minimum overlap of 6 inches and be rolled together with a special flexible rod to keep the ends from separating. Fence posts should be spaced at a distance based on wet soil strength characteristics and post size and strength; generally, the posts are spaced approximately 4 to 6 feet apart. If standard strength fabric is used in combination with wire mesh, the spacing can be larger. Typically, standards and specifications call for the posts to be no more than 10 feet apart. If extra-strength fabric is used without wire mesh reinforcement, some standards call for the support posts to be spaced no more than 6 feet apart (VDCR, 1995). Again, this spacing should depend on wet soil strength characteristics and post size.

A silt fence must provide sufficient storage capacity or be stabilized over flow outlets such that the storage volume of water will not overtop the fence. The return period event (size of the rainfall event managed) used for design is typically a prerogative of the regulatory agency. For temporary fences, a 2-year storm event is typically used as a design standard. Fences that will be in place for 6 months or longer are commonly designed based on a 10-year storm event (Sprague, 1999). The space behind the fence used for impoundment volume must be sufficient to adequately contain the sediment that will be deposited. Each storm will deposit sediment behind the fence, and after a period of time the amount of sediment accumulated will render the fence useless. Frequency of fence management is a function of its sizing (i.e. whether the fence was installed for a 2-year or a 10-year storm event) (Sprague, 1999) and the amount of erosion that occurs in the area draining to the fence.

**Effectiveness**

The performance of silt fences has not been well defined. Laboratory studies using carefully controlled conditions have shown trapping efficiencies in the range of 40 to 100 percent, depending on the type of fabric, overflow rate, and detention time (Barrett et al., 1995; Wyant, 1980; Wishowski et al., 1998). Field studies have been limited and quite inadequate; however, the results show that field-trapping efficiencies are very low. In fact, Barrett et al. (1995) obtained a value of zero percent trapping averaged over several samples with a standard error of 26 percent. Barrett et al. (1995) cite the following reasons for the field tests not showing the expected results:

- Inadequate fabric splices
- Sustained failure to correct fence damage resulting from overtopping
- Large holes in the fabric
- Under-runs due to inadequate “toe-ins”
- Silt fence damaged and partially covered by the temporary placement of stockpiles of materials

Field inspections conducted by Barfield and Hayes (1992) were made in which more than 50 construction sites in South Carolina and Kentucky were visited. Inspections found that silt fence was seldom installed and, when installed, was rarely set up according to specifications. In areas where installations did meet standards, it was obvious that flows sought the weakest spot on the fence and either flowed through cuts in the fabric or undercut or overtopped the fence. This flow was thus changed from the overland flow coming into the site to concentrated flow, causing significant erosion.

Silt fences are effective at removing large particle sediment, primarily aggregates, sands, and larger silts. Sediment is removed through impounding of water to slow velocity. It is argued that the silt fence will not contribute to a reduction in small particle sediment and is not effective against other pollutants (WYDEQ, 1999). EPA (1993) reports the following effectiveness ranges for silt fences constructed of filter fabric: average total suspended solids removal of 70 percent, sand removal of 80 to 90 percent, silt-loam removal of 50 to 80 percent, and silt-clay-loam removal of 0 to 20 percent. However, the EPA numbers from the Nationwide Urban Runoff Program should not be considered to apply to every location. The actual trapping will vary widely for a given design because of differences in hydrologic regimes and soil types.

The advantages of using silt fences include minimal labor requirement for installation, low cost, high efficiency in removing sediment, durability, and sometimes reuse (Sprague, 1999). Silt fences are the most readily available and cost-effective control options where options like diversion are not possible. Silt fences are also a popular choice because contractors have used them extensively and their familiarity makes silt fence use more likely for future construction activities. The visibility of a silt fence is also an advantage (i.e., the fence is "advertising" the use of erosion and sediment control practices). In addition, the silt fence visibility makes site inspection easier for contractors and government inspectors (CWP, 1996).

**Limitations**

Silt fences should not be installed along areas where rocks or other hard surfaces will prevent uniform anchoring of fence posts and entrenching of the filter fabric because an insufficient anchor will greatly reduce their effectiveness and may create runoff channels. In addition, open areas where wind velocity is high may present a maintenance challenge, as high winds may accelerate deterioration of the filter fabric (Smolen et al., 1988). When the pores of the silt fence fabric become clogged with sediment, pools of water are likely to form uphill of the fence. Siting and design of the silt fence should account for this problem, and care should be taken to avoid unnecessary diversion of storm water from these pools which might cause further erosion damage. Silt fences can act as a diversion if placed slightly off-contour and can control shallow, uniform flows from small, disturbed areas and deliver sediment-laden water to deposition areas.

Silt fences will sag or collapse if a site is too large, if too much sediment accumulates, if the approach slope is too steep, or if the fence was not adequately supported. If the fence bottom is not properly installed or the flow velocity is too fast, fence undercuts or blowouts can occur because of excess runoff. Erosion around the end of the fence can occur if the fence ends do not extend upslope to prevent flow around the fence (IDNR, 1992).

**Maintenance**

Site operators should inspect silt fences after each rainfall event to ensure they are intact and that there are no gaps at the fence-ground interface or tears along the length of the fence. If gaps or tears are found, they should be repaired or the fabric should be replaced immediately. Accumulated sediments should be removed from the fence base when the sediment reaches one-third to halfway up the height of the fence. Sediment removal should occur more frequently if accumulated sediment is creating a noticeable strain on the fabric and there is the possibility that the fence might fail from a sudden storm event.

**Cost**

There is a wide range of data on installation costs for silt fences. EPA estimates these costs at approximately $6.00 per linear foot (USEPA, 1992) while SWRPC estimates unit costs between $2.30 and $4.50 per linear foot (SWRPC, 1991). Silt fences have an annual maintenance cost that is 100 percent of installation cost (Brown and Schueler, 1997). These values are significantly greater than that reported by R. S. Means (2000), which indicates a 3-foot-tall silt fence installation cost between $0.68 and $0.92 per linear foot (for favorable and challenging installations). It should be noted that the R. S. Means value covers just a single installation, without the expected costs of maintenance (e.g., removal of collected sediment). In addition, the type of silt fence fabric employed will also affect the total installation costs.

#### 5.1.5.3.2 Super Silt Fence

**General Description**

Super silt fence is a modification of a standard silt fence. The two central differences between the standard silt fence and the super silt fence is that the super silt fence has toe that is buried more deeply and the backing material is chain link fence held in place by steel posts—a concept that originated in Maryland. The Maryland super silt fence requires a Geotextile Class F fabric over a chain link fence to intercept sediment-laden runoff from small drainage areas. The super silt fence provides a barrier that can collect and hold debris and soil more effectively than a standard silt fence, preventing material from entering critical areas. It is best used where the installation of a dike would destroy sensitive areas, woods, and wetlands.

**Applicability**

Super silt fences can be used in the same conditions as a silt fence. Fences should follow the contour of the land. Table 5-15 lists the distance a super silt fence should be from a slope to ensure maximum effectiveness (MDE, 1994).

**Table 5-15. Slope Lengths for Super Silt Fences**

| Slope (%) | Slope Length | |
|---|---|---|
| | **Minimum** | **Maximum** |
| 0-10 | Unlimited | Unlimited |
| 10-20 | 200 feet | 1,500 feet |
| 20-33 | 100 feet | 1,000 feet |
| 33-50 | 100 feet | 500 feet |
| 50+ | 50 feet | 250 feet |

**Design and Installation Criteria**

As with the standard silt fence, design criteria are of two types, hydrologic design for a required trapping of sediment and flow rate to pass the design storm and selection of appropriate installation criteria such that the silt fence will perform as designed.

*Hydrologic Design*

Hydrologic design criteria are the same as the criteria for the standard silt fence.

*Installation Criteria*

The criteria used for the Maryland super silt fence indicate the following, although they have not been tested with field data:

- The fence should be placed as close to the contour as possible, with no section of the silt fence exceeding a grade of 5 percent for a distance of more than 50 feet.
- Fabric should be no more than 42 inches in height and should be held in place with a 6-foot chain link fence.
- Fabric should be attached to the steel pole using wire ties or staples. Fabric should be securely fastened to the chain link fence with ties spaced every 24 inches at the top and midsection.
- Fabric should be embedded into the ground at a minimum of 8 inches.
- Edges of fabric should overlap by 6 inches.

Table 5-16 describes the physical properties of Geotextile class F fabric (MDE, 1994).

**Table 5-16. Minimum Requirements for Super Silt Fence Geotextile Class F Fabric**

| Physical Properties | Requirements |
|---|---|
| Tension Strength | 50 pound/inch |
| Tensile Modulus | 20 pound/inch |
| Flow Rate | 0.3 gallon/ft$^2$/minute |
| Filtering Efficiency | 75% |

**Effectiveness**

Performance data have not been collected for super silt fences. The fences have been proposed for locations within a sensitive watershed, or where site conditions prohibit the use of a standard silt fence. However, until performance data are collected under field conditions, effectiveness is speculative.

**Limitations**

Super silt fences are not as likely to fail structurally as are standard silt fences, but they are more expensive than standard silt fences.

**Maintenance**

Maintenance requirements for super silt fences are generally the same as for standard silt fences.

**Cost**

The cost of the super silt fence is more than the standard silt fence because of deeper burial at the toe and the cost of chain linked fencing. R. S. Means (2000) indicates a rental price of $10 to $11 per linear foot of chain linked fence for periods up to 1 year. Overall, rental is expected for most construction site installation because rental rates are approximately half the price of permanent chain link fencing.

### 5.1.5.3.3 Straw Bale Dike

**General Description**

The straw bale dike is a temporary measure used to trap sediment from small, sloping disturbed areas. It is constructed of straw bales (not hay bales) wedged tightly together and placed along the contour downslope of disturbed areas. The bales are placed in a shallow excavation, and the upslope side is sealed with soil. Stakes are driven through the bales into the soil to help hold the bales in place. The dike works by impounding water, which allows sediment to settle out in the upslope area (Haan et al., 1994). Straw bale dikes are recommended for short duration application and are usually effective for less than 3 months because of rapid decomposition (USDOT, 1995).

## Applicability

Straw bale dikes are generally placed at the toe of fills to provide for a broad shallow sediment pool. The dikes should not be used in drainage areas with concentrated and high flows, in large drainage areas, or in ditches and swales. The location of the straw bale dike should be fairly level, at least 10 feet from the toe, and should follow the land contour. Table 5-17 lists the distance a straw bale dike should be placed from a slope to ensure maximum effectiveness.

**Table 5-17. Maximum Land Slope and Distances Above a Straw Bale Dike**

| Land Slope (%) | Maximum Distance Above Dam (ft) |
|---|---|
| Less than 2 | 100 |
| 2-5 | 75 |
| 5-10 | 50 |
| 10-20 | 25 |
| More than 20 | 15 |

Source: USDOT, 1995.

## Design and Implementation Criteria

*Hydrologic Design*

Hydrologic design dictates the structure necessary to withstand a storm without causing damage while trapping the required amount of sediment. Either a database or some type of model are needed to find the appropriate design. Efforts to model the sediment trapping that occurs in straw bale dikes have resulted in models that predict the settling in the ponded area upstream from the fence (Barfield et al., 1996; Lindley et al., 1998). The results from model simulations show that trapping depends primarily on the surface area of the impounded water and flow rate through the filter. The models use a clear water slurry flow rate to predict discharge. It is anticipated, based on visual observations, that sediment will clog the straw bale barrier, reducing the slurry flow rate. Thus, results from model studies to date are suspect and need to be modified to account for the impact of clogging on flow rate.

*Installation Criteria*

The US DOT's BMP Manual and the Indiana BMP Manual call for bales to be:

- Anchored by driving two 36-inch long (minimum) steel rebars or 2 x 2-inch hardwood stakes through each bale;
- Sized according to the standard bale size of 14 inches x 18 inches x 35 inches;
- Placed in an excavated trench at least 4 inches deep, a bale's width, and long enough that the end bales are somewhat upslope of the sediment pool;

- Abutted tightly against each other; and,

- Sized such that impounded water depth should not exceed 1.5 feet.

The USDOT BMP Manual does not require that straw bale dikes be designed; however, the Indiana Manual limits the drainage area to 1/4 acre per 100 feet of dam and the total drainage area draining to a straw bale dike to 2 acres.

**Effectiveness**

The information on performance of straw bale dikes is very limited. In laboratory studies of bales at varying orientations, Kouwen (1990) found that trapping efficiencies ranged from 60 to 100 percent. Field data on trapping have not been collected; however, visual inspection of sites indicate that straw bales are not properly installed to prevent flows from undercutting or flowing between bales (Barfield and Hayes, 1992, 1999). In addition, bales deteriorate rapidly and need to be replaced frequently. Because of these problems, the use of straw bale dikes as a perimeter control is not recommended, except in special circumstances. Only 27 percent of erosion and sediment control experts rated the straw bale dike as an effective erosion and sediment control practice, although its use was still allowed in half of the communities surveyed (Brown and Caraco, 1997).

**Limitations**

Straw bale dikes should not be used as a diversion, in streams, in channels, or in areas with concentrated flow. The bales are not recommended for paved areas because of the inability to anchor the bales (IDNR, 1992).

Care must be taken to ensure that the bales are not installed in an area where there is a concentrated flow of runoff, in a drainage area that is too large, or on an excessive slope (IDNR, 1992). Under these conditions, erosion around the end of the bales, overtopping and undercutting of the bales, and bale collapsing and dislodging are likely to occur. Overtopping will also occur if the storage capacity is underestimated and where provisions are not made for safe bypass of storm flow (IDNR, 1992). Undercutting will occur if the bales are not entrenched at least 4 inches and backfilled with compacted soil or were not abutted or chinked properly. Straw bale dikes are likely to collapse or dislodge if the bales are not adequately staked, or if too much sediment is allowed to accumulate before cleanout (IDNR, 1992).

**Maintenance**

For the straw bale dike to be most effective, it is important to replace deteriorated bales when appropriate.

**Cost**

The cost of straw bale dikes are relatively low, making their use attractive. R. S. Means (2000) indicates a staked straw bale unit cost of $2.61 per linear foot (Costs include materials, labor, and equipment, with profit and overhead).

### 5.1.5.3.4 Sediment Trap

**General Description**

A sediment trap is a temporary control device used to intercept sediment-laden runoff and to trap sediment to prevent or reduce off-site sedimentation. It is normally a more temporary type of structure than a sediment pond and is constructed to control sediment on the construction area during a selected phase of the construction operation. A sediment trap can be formed by excavation and/or embankments constructed at designated locations accessible for cleanout. The outlet for a sediment trap is typically a porous rock fill structure, which serves to detain the flow, but a pipe structure can also be used. A temporary sediment trap may be located in a drainageway, at a storm drain inlet, or at other points of discharge from a disturbed area. They may be constructed independently or in conjunction with diversions and may be used in most drainage situations to prevent excessive siltation of pipe structures (USEPA, 1992).

**Applicability**

Sediment traps can simplify the storm water control plan design process by trapping sediment at specific spots at a construction site (USEPA, 1992). They should be installed as early in the construction process as possible and are primarily effective as a short-term solution to trapping sediment from construction sites (WYDEQ 1999). Natural drainage patterns should be noted, and sites where runoff from potential erosion can be directed into the traps should be selected. Traps are most effective when capturing runoff from areas where 2 to 5 acres drain to one location. Sediment traps should not be located in areas where their failure resulting from excess runoff can lead to further erosive damage of the landscape. Alternative diversion pathways should be designed to accommodate these potential overflows. Traps should be accessible for clean-out and located so that they do not interfere with construction activity. In addition, the traps are easily adaptable to most conditions.

**Design and Implementation Criteria**

*Hydrologic Design*

A sediment trap should be designed to maximize surface area and sediment settling. This will increase the effectiveness of the trap and decrease the likeliness of backup during and after periods of high runoff intensity. The design of a trap includes determining the storage volume, surface area, dimensions of spillway or outlet, and elevations of embankment (USDOT, 1995). Sediment traps should be designed to meet a 2-year, 24-hour storm event, but the selection of a return period varies among regulatory agencies (IDNR, 1992).

Storage volume is created by a combination of excavation of land and construction of an embankment to detain runoff (USDOT, 1995). Trap storage volume and length of spillway are determined as a function of the runoff volume and rate for the design storm. These parameters will vary depending on return period rainfall and watershed hydrologic characteristics. Some standards specify a storage volume per acre disturbed. For example, Smolen et al. (1998) specified that approximate storage capacity of each trap should be at least 67 cubic yards per acre disturbed draining into the trap, but more recent guidelines suggest 134 cubic yards per acre of drainage area (VDCR, 2001). Any national standard, however, should be based on runoff volume and peak discharge to be generally applicable. Local regulations can translate this into applicable volume and area standards.

A more important criterion than storage volume relates to sediment trapping. If a trapping efficiency is specified, as in the case of South Carolina (SCDHEC, 1995), it is necessary to design for trapping efficiency. If a TSS or settleable solids effluent criterion is adopted (SCDHEC, 1995), settleable solids must be estimated. In both cases, a national standard should address how to estimate trapping efficiency or settleable solids. Efforts to model the sediment trapping that occurs in sediment traps have resulted in models that predict the settling in the ponded area (Barfield et al., 1996; Lindley et al., 1998). The results from model simulations show that trapping depends primarily on surface area of the impounded water and flow rate through the rock fill outlet. In fact, the ratio of peak outflow rate to surface area is the best simple predictor of trapping. The models use a modification of the Herrera and Felton (1991) relationship developed by Haan et al. (1994) to predict discharge rates. The predicted flow rates do not take into account clogging that can occur in rock fill. No models or procedures are available to estimate this clogging or its impact on flow criteria.

Design aids have also been developed for sediment traps, using simulations from the SEDIMOT III (Barfield et al., 2001; Hayes et al., 2001). In the model, predictions are made of trapping efficiency using the ratio of settling velocity for the $d_{15}$ of the eroded sediment, divided by the ratio of discharge to ponded surface area. The design aid yields conservative estimates, but the database used for generating the design aid is based on the assumption that flow rates are not impacted by clogging. This latter assumption is not likely to be a critical issue, but should be addressed in future research.

*Installation Specifications*

USDOT standards call for the embankment to be constructed of compacted earth, at a maximum height of 5 feet (1.5 meters), a width of 4 to 5 feet (1.2 meters), and side slopes of 2:1or flatter. These values may change as a result of local criteria and with changing soil characteristics. Temporary vegetation should be applied to the embankment.

Two types of outlet structures are typically used for sediment traps, a rock outlet and a pipe outlet. Spillways of large stones or aggregate are the most common type of outlet designed for sediment traps. The crest of the spillway should be constructed 1 foot below the top of the embankment and the spillway depth 1.5 feet below the top of the embankment. Weir length of the spillway is determined based on the contributing drainage area (Table 5-18) (USDOT, 1995). The outlet apron should be a minimum of 5 feet long, and situated on level ground with a filter fabric foundation to ensure exit velocity of drainage to receiving stream is nonerosive (IDNR, 1992).

The length of the rock outlet should be determined based on peak discharge required and rock characteristics, typically rock diameter. Flow rate calculations can be made with the relationship of Herrera and Felton (1991) as modified by Haan et al. (1994). Alternatively, the USDOT has specified the weir length for a given drainage area as shown in Table 5-18. However, the values should be adjusted for each climatologic area to account for local hydrologic and return period rainfall.

**Table 5-18. Weir Length for Sediment Traps**

| Contributing Drainage Area | Weir Length (ft) |
|---:|---:|
| 1 | 4 |
| 2 | 5 |
| 3 | 6 |
| 4 | 10 |
| 5 | 12 |

Source: USDOT, 1995.

The pipe outlet, constructed of corrugated metal or PVC pipe riser, is an alternative to the rock outlet. Pipe diameter is based on the peak discharge rate required. To obtain appropriate freeboard, the top of pipe should be placed 1.5 feet below embankment elevation. Perforated pipe is sometimes used. USDOT suggests perforations of 1-inch (25 mm) diameter holes or 0.5 x 6 inch (13 x 15 mm) slits in the upper two-thirds of the pipe; however, the discharge should be calculated for this pipe specification to ensure that it matches the required peak discharge.

The pipe should be placed vertically and horizontally above wet storage elevation (USDOT, 1995). Riprap should be used as an outlet protection and placed at the outlet of the barrel to prevent scour from occurring (USDOT, 1995). A stable channel should be provided to convey discharge to the receiving channel (USDOT, 1995).

**Effectiveness**

If it is assumed that the flow can be accurately controlled by the rock fill outlet, sediment traps should operate as effectively as sediment basins, with trapping efficiencies reduced as a result of smaller surface areas. The NURP study (USEPA, 1993), Stahre and Urbonas (1990), and Haan, et al., (1994), report that sediment basins effectively trapped sediment and chemicals as shown in Table 5-19.

**Table 5-19. Range of Measured Pollutant Removal for Sediment Detention Basins**

| Item | Removable Percentage |
|---|---|
| Total suspended solids (TSS) | 50-70 |
| Total phosphorus (TP) | 10-20 |
| Nitrogen | 10-20 |
| Organic matter | 20-40 |
| Lead | 75-90 |
| Zinc | 30-60 |
| Hydrocarbons | 50-70 |
| Bacteria | 50-90 |

Source: Stahre and Urbonas, 1990.

Information on the actual effectiveness of sediment traps is limited. The discussion should start first with the flow hydraulics of the rock fill outlet typically employed as a principal spillway for sediment traps. Procedures for estimating flow through rock fill have been developed by Herra and Felton (1991) to estimate flow as a function of average rock diameter, standard deviation of rock size, and flow length. If these parameters could be controlled in an actual situation, the flow could be accurately predicted. However, given that standard construction practices consist of end-dumping the rock fill in place, one would expect little correlation between design and construction and the actual discharge and trapping efficiency would be expected to be dramatically different from the design. This analysis does not mean that sediment traps are ineffective, but that a given design could not be guaranteed to meet the effluent criteria, even though the predictions indicate compliance. Sediment trapping efficiency is a function of surface area and inflow rate (Smolen et al., 1988). Those traps that provide pools with large length-to-width ratios have a greater chance of success.

Sediment traps remove larger sized sediment, primarily sized from silt to sands, by slowing water velocity and allowing for sediment settling in ponded water (Haan et al., 1994). Although sediment traps allow for settling of eroded soils, because of their short detention periods for storm water they typically do not remove fine particles such as silts and clays without chemical treatment. Sediment settling ability is related to the square of the particle size; halving particle sizes quadruples the time needed to achieve settlement (WYDEQ 1999). To increase overall effectiveness, traps should be constructed in smaller areas with low slopes.

Sediment traps are typically designed to remove only sediment from surface water, but some non-sediment pollutants are trapped as well (Haan et al., 1994).

**Limitations**

Common concerns associated with sediment traps are included in Table 5-20.

**Table 5-20. Common Concerns Associated with Sediment Traps**

| Common Concern | Result |
|---|---|
| Inadequate spillway size | Results in overtopping of the dam and possible failure of the structure |
| Omission or improper installation of geotextile fabric | Results in piping under the sides or bottom of the stone and outlet section |
| Low point in embankment caused by inadequate compaction and settling | Results in overtopping and possible failure |
| Stone outlet apron does not extend to stable grade | Results in erosion below the dam |
| Stone size too small or backslope too steep | Results in stone displacement |
| Inadequate vegetative protection | Results in erosion of embankment |
| Sediment not removed from the basin with enough frequency | Results in inadequate storage capacity |
| Contact slope between stone spillway and earth embankment too steep | Results in piping failure |
| Outlet pipe installed in vertical side of trench | Results in piping failure of embankment |
| Corrugated tubing used as outlet pipe | Results in crushed pipe and inadequate outlet capacity |

Source: IDNR, 1992.

**Maintenance**

The primary maintenance consideration for temporary sediment traps is the removal of accumulated sediment from the basin, which must be done periodically to ensure the continued effectiveness of the sediment trap. Sediments should be removed when the basin reaches approximately 50 percent sediment capacity.

A sediment trap should be inspected after each rainfall event to ensure the trap is draining properly. Inspectors should also check the structure for damage from erosion or piping. The depth of the spillway should be checked and maintained at a minimum of 1.5 feet below the low point of the trap embankment.

**Cost**

The cost of installing temporary sediment traps ranges from $0.20 to $2.00 per cubic foot of storage (about $1,100 per acre of drainage). EPA estimated the following costs for sediment traps, which vary as a function of the volume of storage: $513 for 1,800 cubic yards, $1,670 for 3,600 cubic yards, and $2,660 for 5,400 cubic yards (USEPA, 1993). Evaluation of a series of more recent data sources (USEPA, 2003) indicated that sediment traps have an average cost of $0.30 per cubic foot of storage. In addition, it has been reported that a sediment trap has an annual maintenance cost of 20 percent of installation cost (Brown and Schueler, 1997).

### 5.1.5.3.5 Sediment Basin

**General Description**

A sediment basin is a storm water detention structure formed by constructing a dam across a drainageway or excavating a storage volume at other suitable locations and using it to intercept sediment-laden runoff. Sediment basins are generally larger and more effective in retaining sediment than temporary sediment traps and typically remain active throughout the construction period. Jurisdictions that require postdevelopment flow to be less than or equal to predevelopment flow during construction may employ the designed detention facilities as a temporary sediment basin during construction.

When sediment basins are designed properly, they can control sediment pollution through the following functions (Faircloth, 1999):

- Sediment-laden runoff is caught to form an impoundment of water and create conditions where sediment will settle to the bottom of the basin.

- Treated runoff is released with less sediment concentration than when it entered the basin.

- Storage is provided for accumulated sediment, and resuspension by subsequent storms is limited.

**Applicability**

Sediment basins should be located at a convenient concentration point for sediment-laden flows (NCDNR, 1988). Ideal sites are areas where natural topography allows a pond to be formed by constructing a dam across a natural swale; such sites are preferred to those that require excavation (Smolen et al., 1988).

Sediment basins are also applicable in drainage areas where it is anticipated that other erosion controls, such as sediment traps, will not be sufficient to prevent off-site transport of sediment. Choosing to construct a sediment basin with either an earthen embankment or a stone/rock dam will depend on the materials available, location of the basin, and desired capacity for storm water runoff and settling of sediments.

Rock dams are suitable where earthen embankments would be difficult to construct or where riprap is readily available. Rock structures are also desirable where the top of the dam structure is to be used as an emergency overflow outlet. These riprap dams are best for drainage areas of less than 50 acres. Earthen damming structures are appropriate where failure of the dam will not result in substantial damage or loss of property or life. If properly constructed, sediment basins with earthen dams can handle storm water runoff from drainage basins as large as 100 acres.

## Design and Implementation Criteria

Hydrologic Design

A sediment basin can be constructed by excavation or by erecting an earthen embankment across a low area or drainage swale. Sediment basins can be designed to drain completely during dry periods, or they can be constructed so that a shallow, permanent pool of water remains between storm events. Depending on the size of the basin constructed, the basin may be subject to additional regulation, particularly state and federal regulations related to dam safety.

Sediment basins can be used for any size watershed, but the U.S. Department of Transportation recommends a drainage area range of 5 to 100 acres (USDOT, 1995). Components of a sediment basin that must be considered in the hydrologic design include the following (Haan et al., 1994):

- A sediment storage volume sized to contain the sediment trapped during the life of the structure or between cleanouts.

- A permanent pool volume (if included) above the sediment storage to protect trapped sediment and prevent resuspension as well as providing a first flush of discharge that has been subjected to an extended detention period.

- A detention volume that contains storm runoff for a period sufficient to trap the necessary quantity of suspended solids.

- A principal spillway that can be a drop-inlet pipe and barrel, a trickle tube, or other type of controlled release structure.

- An emergency spillway that is designed to handle excessive runoff from the rarer events and prevent overtopping.

The following recommended procedures for conducting the hydrologic design are summarized from Haan et al. (1994).

**Sediment Storage Volume.** This volume should be sufficient to store the sediment trapped during the life of the structure or between cleanouts. Sediment storage volume can be calculated based on sediment yield using relationships such as the Revised Universal Soil Loss Equation with an appropriate delivery ratio (Renard et al., 1994) or a computer model such as SEDIMOT III (Barfield et al., 1996) or SEDCAD (Warner, 1998). Many design specifications, however, base the sediment storage volume on a volume per acre disturbed. This volume is highly site-specific, depending on rainfall distributions, soil types, and construction techniques. It is recommended that care be exercised in developing appropriate values to be sure that variations in rainfall throughout a state or region are incorporated in statutory requirements.

**Permanent Pool Volume.** Providing a first flush of discharge that has been subjected to an extended detention period can help to minimize degradation of water quality and justify some permanent pool. The recommended capacity of the permanent pool varies with the regulatory agency. The U.S. Department of Transportation, for example, recommends 67 cubic yards per acre (126 $m^3$/ha) (USDOT, 1995). If an effluent criterion such as allowable peak TSS or peak settleable solids is used, the final design of both permanent pool and detention volume should be selected only after using a computer model to predict the expected peak effluent concentrations.

**Detention Volume.** Storm runoff must be contained for a period of time sufficient to trap the necessary quantity of suspended solids. Since inflow is occurring simultaneously with outflow, the detention time for each plug of flow is different and should be considered individually. The size of the detention volume, as stated above, should also be developed in concert with determining the size of the permanent pool volume as well as the size of the principal spillway. When effluent TSS and settleable solids criteria are used, the size of the detention volume and permanent pool volume should be determined through a computer model calculation of expected effluent concentrations for a given design. The return period used to size the detention volume depends on the regulatory agency, but a return period of 10 years is typical for sediment basins that eventually become storm water detention ponds (i.e., are used to limit future flooding due to storm water). EPA's review of State construction site regulations found the majority of States specify detention volume in terms of cubic feet per acre that drains to the sediment basin. State design values range between 1,800 and 5,400 cubic feet per acre, with 3,600 cubic feet per acre as the typical value.

**Principal Spillway.** The principal spillway is a hydraulic outlet structure sized to provide the appropriate outflow rate to meet the effluent or trapping efficiency criteria. The principal spillway should have a dewatering device that slowly releases water contained in the detention storage over an extended period of time and at a rate determined to trap the required amount of sediment and/or provide for the appropriate effluent concentration in the design storm. The more common outlet structures are the drop-inlet structure and the trickle tube. Sizing of the principal spillway should follow standard design procedures with respect to hydrology and sediment considerations, but sizing the structure to simply pass the design storm is inappropriate and will not result in meeting an effluent or trapping efficiency standard. The size to be used in a given structure should be determined based on the effluent or trapping efficiency standard being targeted and site-specific hydrologic and soil conditions. Appropriate design will require the use of a computer model such as SEDIMOT III (Barfield et al., 1996) or design aids such as those developed for South Carolina (Hayes and Barfield, 1995). In general, the design is developed to maximize surface area, which will minimize peak discharge. Since failure of the dam could result in downstream damage, the design should be done and certified by a licensed engineer with expertise in hydrologic computation.

It has been proposed that a surface skimmer made of PVC, aluminum, or stainless steel and designed to prevent trash from clogging can also be used to replace conventional principal spillways. The skimmer puts the basin drain just below the water surface, allowing for a constant head rather than variable head from the bottom. It is proposed that the skimmer allows water to be released from the top of the basin, which would be the cleanest water, and that the skimmer properly regulates the filling and draining of the basin (Fairchild, 1999). The skimmer floats on the surface of the basin and rises as water in the basin rises during a storm. After the storm the skimmer slowly releases water from the basin. As the basin drains, the skimmer settles to the bottom, draining the entire pool except for a pool directly under the skimmer. The skimmer can be attached directly to an outlet pipe that drains through the dam or can be attached to an outlet pipe through a riser. It is important to point out that use of the skimmer is controversial and not universally recognized as a good concept. Conventional hydraulic flow theory would not concur with the statement that the flow would come only from the surface, unless the pond had significant thermal gradients preventing flow from deeper levels. A single hole placed just above the sediment cleanout level can also dewater the basin slowly.

**Emergency Spillway.** Since overtopping of the dam can cause failure and downstream damage, an emergency spillway is necessary to handle excessive runoff from the larger, less frequent events and prevent overtopping. The design storm for the emergency spillway will depend on the hazard classification of the sediment basin. Typical return periods vary between 25 and 100 years, with 25 years recommended by the USDOT. Sizing of the emergency spillway is typically accomplished to simply transmit the rare event without eroding the base of the spillway. Procedures for making the hydrologic and hydraulic computations are summarized in Haan et al. (1994). Again, since failure of the dam could result in downstream damage, the design should be done and certified by a licensed engineer with expertise in hydrologic computation.

### Installation Criteria

The embankment for permanent sediment basins should be designed using standard geotechnical construction techniques. The fill is typically constructed of earthen fill material placed and compacted in continuous layers over the entire length of the fill. USDOT recommends 6- to 8-inch layers (USDOT, 1995). The embankment should be stabilized with vegetation after construction of the basin. A cutoff trench should be excavated along the centerline of the dam to prevent excessive seepage beneath the dam and be sized using standard geotechnical computations. USDOT recommends that a minimum depth of the cutoff trench should be approximately 2 feet (600 mm), the height should be to the riser crest elevation, the minimum bottom width should be 4 feet (1.2 m) or wide enough for compaction equipment, and slopes should be no steeper than 1:1.

Sediment basins can also be constructed with rock dams in a design that is similar to a sediment basin with an earthen embankment. It is important to remember that rock fill is highly heterogeneous and that flow rates calculated with any available procedure are not likely to match those that will actually occur. Since sediment trapping is inversely proportional to flow rate, the trapping efficiency will be impacted significantly. No data are available to determine the variability of rock fill in actual installations so that confidence intervals can be placed on predicted flow rates. Such data should be collected and the confidence intervals calculated prior to recommending the use of rock dams as outlets on any structures other than sediment traps.

**Effectiveness**

The effectiveness of a sediment basin depends primarily on the sediment particle size and the ratio of basin surface area to inflow rate (Smolen et al., 1988; Haan et al., 1994). Basins with a large surface area-to-volume ratio will be most effective. Studies by Barfield and Clar (1985) showed that a surface area-to-peak discharge ratio of 0.01 acres per cubic foot would trap more than 75 percent of the sediment coming from the Coastal Plain and Piedmont regions in Maryland. This efficiency might vary for other regions of the country and should not be used as a national standard. Studies by Hayes et al. (1984) and Stevens et al. (2001), however, show that similar relationships can be developed for other locations.

Laboratory data collected on pilot-scale facilities are available on the trapping efficiency of sediment basins, effluent concentrations, dead storage and flow patterns, and the impacts of chemical flocculants on sediment trapping (Tapp et al., 1981; Wilson and Barfield, 1984; Griffin et al., 1985; Jarrett, 1999; Ward et al., 1977, 1979). In general, the laboratory studies show that pilot-scale ponds can be expected to trap 70 to 90 percent of sediment, depending on the sediment characteristics, pond volume, and flow rate. The trapping efficiency and effluent concentration are, in general, related to the overflow rate and can be reasonably well predicted using a plug flow model (Ward et al., 1977, 1979) and a Continuously Stirred Tank Reactor (CSTR) model (Wilson et al., 1982; Wilson et al., 1984). Extensive field-scale data are available on long term trapping efficiency in storm water detention basins (Brune, 1953) in which the annual trapping efficiency is related to the annual capacity inflow ratio of the basin. These structures are not representative of those used for sediment ponds but would be representative of those used for regional detention. A more limited database is available on single storm sediment trapping in the larger structures (Ward, et al., 1979) and on a field laboratory structure at Pennsylvania State University (Jarret et al., 1999).

For maximum trap efficiency, Smolen et al. (1988) recommend the following:

- Allow the largest surface area possible, maximize the length-to-width ratio of the basin to prevent short circuiting, and ensure use of the entire design settling area;
- Locate inlets for the basin at the maximum distance from the principal spillway outlet;
- Allow the maximum reasonable time to detain water before dewatering the basin; and,
- Reduce the inflow rate into the basin and divert all sediment-free runoff.

Jarett (1999) has shown that the smaller the depth of the basin, the more sediment is discharged. A 0.15-meter-deep (0.49-foot-deep) basin lost twice as much sediment as a 0.46-meter-deep (1.50-foot-deep) basin. Jarrett also found that the performance of a sediment basin will increase with the use of a skimmer in the principal spillway. The sediment discharged was 1.8 times greater with only a perforated riser than with a skimmer in the principal spillway. In addition, increasing the dewatering time, which will allow for more sediment deposition, decreases the sediment loss from the basin (Jarett, 1999).

**Limitations**

Neither a sediment basin with an earthen embankment nor a rock dam should be used in areas of continuously running water (live streams). The use of sediment basins is not intended for areas where failure of the earthen or rock dam will result in loss of life, damage to homes or other buildings, or interference with the use of public roads or utilities.

Because sediment basins are usually temporary structures, they are often designed poorly and rarely receive adequate attention and maintenance. As a result, these basins will not achieve the function for which they were designed, especially when conventional outlets cannot properly meter outflow to create an impoundment, thus allowing rapid release of sediment-laden water from the bottom of the basin to escape (Faircloth, 1999).

Common concerns associated with sediment basins are included in Table 5-21.

**Table 5-21. Common Concerns Associated with Sediment Basins**

| Common Concern | Result |
|---|---|
| Improper compaction, omission of anti-seep collar, leaking pipe joints, or use of unsuitable soil | Results in piping failure along conduit |
| Inadequate vegetation or improper grading and sloping | Results in erosion of spillway or embankment slopes |
| Inadequate compaction or use of unsuitable soil | Results in slumping or settling of embankment |
| Steep side slopes | Results in bank failure due to slumping |
| Inadequate outlet protection | Results in erosion and caving below principal spillway |
| Basin not located properly for access | Results in difficult, ineffective, and costly maintenance |
| Sediment not properly removed | Results in inadequate storage capacity and potential resuspension |
| Lack of anti-flotation measures | Results in the riser and barrel being blocked with debris |
| Principal and emergency spillway on design plans | Results in improper disposal of accumulated sediment |
| Gravel clogging the dewatering system | Results in a safety or health hazard from pond water |
| Principal spillway too small | Results in frequent operation of emergency spillway and increased erosion potential |

Source: IDNR, 1992.

**Maintenance**

Routine inspection and maintenance of sediment basins is essential to their continued effectiveness. Basins should be inspected after each storm event to ensure proper drainage from the collection pool and determine the need for structural repairs. Erosion from the earthen embankment or stones moved from rock dams should be repaired or replaced immediately.

Sediment basins must be located in an area that is easily accessible to maintenance crews for removal of accumulated sediment. Sediment should be removed from the basin when its storage capacity has reached approximately 50 percent. Trash and debris from around dewatering devices should be removed promptly after rainfall events.

**Cost**

If constructing a sediment basin with less than 50,000 cubic feet of storage space, the cost of installing the basin ranges from $0.20 to $1.30 per cubic foot of storage (approximately $1,100 per acre of drainage) with an average cost of approximately $0.60 per cubic foot of storage (USEPA, 1993). If constructing a sediment basin with more than 50,000 cubic feet of storage space, the cost of installing the basin ranges from $0.10 to $0.40 per cubic foot of storage (approximately $550 per acre of drainage) with an average cost of approximately $0.30 per cubic foot of storage (USEPA, 1993). A review of state highway project bids and county bonding estimates conducted in 2003 confirmed this value of $0.30 per cubic foot (USEPA, 2003). Annual maintenance costs are 25 percent of installation costs (Brown and Schueler, 1997).

As an alternative costing method, designers can use cost curves developed for permanent basins used to manage storm water from urban areas. However, since permanent storm water basins typically include design features that would not be included in temporary sediment basins, this approach is expected to greatly overestimate the actual costs to construct sediment basins. For many sites, sediment basins installed for erosion and sediment control during the construction phase are retained/modified to meet other runoff management requirements. For example, site flood prevention requirements for the 10-year rainfall event can be met with a pond made from a converted sediment basin. As a result, sediment basin installation costs are partially offset by a later cost reduction or savings. Work by the Center for Watershed Protection (1996) provides capital cost equations for different types of sediment basins for permanent installations. For example, for dry extended detention ponds, the following equation can be used to estimate costs:

$$CC = 8.16\,(Vs)^{0.78}$$

For all ponds regardless of type (including wet ponds), the following equation can be used:

$$CC = 20.18\,(Vs)^{0.70}$$

Where:
CC = base construction cost, not including design, engineering, and contingencies
Vs = Storage volume below the crest of the emergency spillway, in cubic feet

Design, engineering, and contingency costs are given as approximately 32 percent of the base construction costs. Base construction costs for permanent ponds are composed of approximately 48 percent excavation/grading cost, 36 percent control structure cost, and 16 percent appurtenances cost. R. S. Means (2000) suggests the cost to remove the eroded sediment collected in a small basin during construction is approximately $4 per cubic yard (this value includes a 100 percent surcharge for wet excavation). Disposal of material on-site will result in an additional cost that can only be computed from site-specific conditions. The cheapest management of dredged material is application to land areas adjacent to the basin followed with application of a vegetative cover.

### 5.1.5.4 Other Control Practices

#### 5.1.5.4.1 Stone Outlet Structure

**Description**

A stone outlet structure is a temporary stone dike installed in conjunction with and as a part of an earth dike. The purpose of the stone outlet structure is to impound sediment-laden runoff, provide a protected outlet for an earth dike, provide for diffusion of concentrated flow, and allow the area behind the dike to dewater slowly. The stone outlet structure can extend across the end of the channel behind the dike or be placed in the dike itself. In some cases, more than one stone outlet structure can be placed in a dike.

**Applicability**

Stone outlet structures apply to any point of discharge where there is a need to discharge runoff at a protected outlet or to diffuse concentrated flow for the duration of the period of construction. The drainage area to this practice is typically limited to one-half acre or less to prevent excessive flow rates. The stone outlet structure should be located so as to discharge onto an already stabilized area or into a stable watercourse. Stabilization should consist of complete vegetative cover and paving that are sufficiently established to be erosion resistant.

**Design and Installation Criteria**

Design criteria are of two types, hydrologic design for a required trapping of sediment and/or flow rate to pass the design storm; and selection of appropriate installation criteria such that the stone outlet will perform as designed.

*Hydrologic Design*

The hydrologic design should be based on the design storm and standard hydraulic calculations. It should include the following considerations:

- Design rainfall and design storm. The design storm should be specified by the regulatory authority. Typically a return period of 2 to 5 years is used. Runoff rates should be calculated with standard hydrologic procedures as allowed by the regulatory authority.

- Drainage area. The drainage area to this structure is typically limited to less than half an acre to ensure that the flow rates are not excessive.

- Length of crest and height of stone fill. The crest length and height of stone fill should be of sufficient size to transmit the design storm without overtopping. The volume of water stored behind the dike can be estimated, but would require routing the storm flow in the design storm. Flow through the stone outlet can be calculated using the relationships of Herrera and Felton (1991) as modified by Haan et al. (1994). The height of the fill should be small enough to prevent excessive flow velocities through the stone fill and prevent undercutting.

- Outlet stabilization. The discharge from the stone outlet should be stabilized with vegetated waterways or riprap until the flow reaches a stable channel. Design of the stabilized outlet should follow procedures presented earlier.

*Installation Criteria Specifications*

A stone outlet structure should conform to the following specifications:

- The outlet should be composed of 2- to 3-inch stone or recycled concrete, but clean gravel may be used if stone is not available.

- The crest of the stone dike should be at least 6 inches lower than the lowest elevation of the top of the earth dike and should be level.

- The stone outlet structure should be embedded into the soil a minimum of 4 inches.

- The minimum length of the crest of the stone outlet structure should be 6 feet.

- The baffle board should extend 1 foot into the dike and 4 inches into the ground and be staked in place.

- The drainage area to this structure should be less than half an acre.

### 5.1.5.4.2 Rock Outlet Protection

**Description**

Rock outlet structures are rocks that are placed at the outfall of channels or culverts to reduce the velocity of flow in the receiving channel to nonerosive rates.

**Applicability**

This practice applies where discharge velocities and energies at the outlets of culverts are sufficient to erode the next downstream reach and is applicable to outlets of all types such as sediment basins, storm water management ponds, and road culverts.

**Design and Installation Criteria**

*Hydrologic Design*

Hydrologic design consists primarily of selecting the design runoff rate and sizing outlet protection. Standard hydrologic calculations should be used with an appropriate return period storm for the outlet being protected (typical return periods range from 2 to 10 years).

The process for sizing outlet protection involves selecting the type and geometry of the outlet protection and the size of the rock lining. The outlet protection may consist of a plunge pool (scour hole), an apron-type arrangement, or an energy dissipation basin (Haan et al., 1994). The design of each differs. Plunge pools are typically used for outlet pipes that are elevated above the water surface. Aprons are used for other types of outlets. Plunge pool geometry is based on the flow rate, pipe size and slope, tailwater depth, and size of the riprap lining (Haan et al., 1994). Apron dimensions are determined by the ratio of the tailwater depth to pipe diameter (Haan et al., 1994). Energy dissipation basins are used as an alternative to the plunge pool. Dimensions are a function of the brink depth in the pipe at the design flow, pipe diameter, and size of riprap (Haan et al., 1994). The size of the rock lining is a function of the discharge, pipe size, tailwater depth, and geometry selected. Details on sizing the rock are given in Haan et al. (1994).

The design method presented here applies to the sizing of rock riprap and gabions to protect a downstream area. It does not apply to rock lining of channels or streams. The design of rock outlet protection depends entirely on the location. Pipe outlets at the top of cuts or on slopes steeper than 10 percent cannot be protected by rock aprons or riprap sections due to reconcentration of flows and high velocities encountered after the flow leaves the apron.

*Installation Criteria*

The following criteria should be considered:

- Bottom grade: The outlet protection apron should be constructed with zero slope along its length. There should be no obstruction at the end of the apron. The elevation of the downstream end of the apron should be equal to the elevation of the receiving channel or adjacent ground.

- Alignment: The outer protection apron should be located so that there are no beds in the horizontal alignment.

- Materials: The outlet protection may be accomplished using rock riprap or gabions. Riprap should be composed of a well-graded mixture of stone sized so that 50 percent of the pieces, by weight, should be larger than the size determined using charts. The minimum $d_{50}$ size to be used should be 9 inches. A well-graded mixture is defined as a mixture composed primarily of larger stone sizes but with a sufficient mixture of other sizes to fill the smaller voids between the stones. The diameter of the largest stone in such a mixture should be 2 times the size selected in Table 5-22 (MDE, 1994).

- Thickness: The SHA riprap specification values are summarized in Table 5-22.

**Table 5-22. Riprap Sizes and Thicknesses (SHA Specifications)**

| | $D_{50}$ (inches) | $D_{100}$ (inches) | Thickness (inches) |
|---|---|---|---|
| Class I | 9.5 | 15 | 19 |
| Class II | 16 | 24 | 32 |
| Class III | 23 | 34 | 46 |

- Stone Quality: Stone for riprap should consist of field stone or rough-hewn quarry stone. The stone should be hard and angular and of a quality that will not disintegrate on exposure to water or weathering. The specific gravity of the individual stones should be at least 2.5. Recycled concrete equivalent may be used provided it has a density of at least 150 pounds per cubic foot and does not have any exposed steel or reinforcing bars.

- Filters: A layer of material placed between the riprap and the underlying soil surface can prevent soil movement into and through the riprap to prevent piping, reduce uplift pressure, and collect water. Riprap should have a filter placed under it in all cases. A filter can be of two general forms: a gravel layer or a geotextile.

- Gabions: Gabion baskets may be used as rock outlet protection, provided they are made of hexagonal triple twist mesh with heavily galvanized steel wire. The maximum lined dimension of the mesh opening should not exceed 4.5 inches. The area of the mesh opening should not exceed 10 square inches. Gabions should be fabricated in such a manner that the sides, ends, and lid can be assembled at the construction site into a rectangular basket of the specified sizes.

Gabions should be of a single unit construction and should be installed according to the manufacturer's specifications. Foundation conditions should be the same as for placing rock riprap. Geotextiles should be placed under all gabions, and gabions must be keyed in to prevent undermining of the main gabion structure.

- The subgrade for the filter, riprap, or gabion should be prepared to the required lines and grades. Any fill required in the subgrade shall be compacted to a density of approximately that of the surrounding undisturbed material.

- The rock or gravel should conform to the specified grading limits when installed in the riprap or filter, respectively.

- Geotextiles should be protected from punching, cutting, or tearing. Any damage other than occasional small holes should be repaired by placing another piece of geotextile fabric over the damaged part or by completely replacing the geotextile fabric. All overlaps, whether for repairs or for joining two pieces of geotextile fabric, should be a minimum of 1 foot in length.

- Stone for the riprap or gabion outlets may be placed by equipment. They should be constructed to the full course thickness in one operation and in such a manner as to avoid displacement of underlying materials. Care should be taken to ensure that the stone is not placed so that rolling will cause segregation of stone by size, i.e., the stone for riprap or gabion outlets should be delivered and placed in a manner that will ensure that it is reasonably homogeneous, with smaller stones filling the voids between larger stones. Riprap must be placed in a manner to prevent damage to the filter blanket or geotextile fabric. Hand placement will be required to the extent necessary to prevent damage to the permanent works.

- Stone should be placed so that it blends in with the existing ground and the depth to the stone surface is sufficient to transmit the flow without spilling over onto the unprotected surface.

**Effectiveness**

There is currently no information on the effectiveness of rock outlet structures.

**Limitations**

Common problems with rock outlet structures include the following:

- If the foundation is not excavated deeply or wide enough, the flow cross-section might be restricted, resulting in erosion around the apron and scour holes at the outlet. Also, the riprap apron should be placed on a suitable foundation to prevent downstream erosion.

- If the riprap that is installed is smaller than specified, rock displacement might result; selectively grouting over the rock materials may stabilize the installation.

- If the riprap is not extended enough to reach a stable section of the channel, downstream erosion could result.

- If a filter is not installed under the riprap, stone displacement and erosion of the foundation might result.

**Maintenance**

Once a riprap outlet has been installed, the maintenance needs are very low. It should be inspected after high flows to see if scour has occurred beneath the riprap, if flows have occurred outside the boundaries of the riprap and caused scour, or if any stones have been dislodged. Repairs should be made immediately.

**Cost**

R. S. Means (2000) indicates machine-placed riprap costs of approximately $40 per cubic yard. For a riprap maximum size between 15 and 24 inches, a cubic yard of riprap will cover between 13.5 and 17 square feet at channel bed (assuming depth of riprap as given in Table 5-22). This suggests that riprap lining will be between $21 and $27 per square foot of outlet (includes materials, labor, and equipment, with overhead and profit). R. S. Means (2000) provides a cost range for gabions ($2.80 to $9 per square foot of coverage) for stone fill depths of 6 to 36 inches, respectively. These costs include all costs of materials, labor, and installation.

### 5.1.5.4.3 Sump Pit

**Description**

A sump pit is a temporary pit from which pumping is conducted to remove excess water while minimizing sedimentation. The purpose of the sump pit is to filter water being pumped to reduce sedimentation to receiving streams.

**Applicability**

Sump pits are constructed when water collects and must be pumped away during excavating, cofferdam dewatering, maintenance or removal of sediment traps and basins, or other uses as applicable, such as for concrete wash out.

**Design and Installation Criteria**

*Hydrologic Design*

The only hydrologic calculation is determining the expected flow rate and volume to be handled. This should follow standard hydrologic computational procedures based on design rainfall, surface and soil conditions, and the size of the pump.

*Installation Criteria and Specifications*

The number of sump pits and their locations should be determined by the designer and included on the plans. Contractors may relocate sump pits to optimize use, but discharge location changes should be coordinated with inspectors.

A perforated vertical standpipe should be wrapped with ½-inch hardware cloth and geotextiles and then placed in the center of an excavated pit, which is then backfilled with filter material ranging from clean gravel to stone. Water is then pumped from the center of the standpipe to a suitable discharge area such as into a sediment trap, sediment basin, or stabilized area.

A sump pit should conform to the following specifications:

- Pit dimensions are variable, with the minimum diameter being twice the diameter of the standpipe.
- The standpipe should be constructed by perforating a 12- to 36-inch diameter pipe, then wrapping it with ½-inch hardware cloth and geotextiles. The perforations should be ½-inch slits or 1-inch diameter holes placed 6 inches on center.
- The standpipe should extend 12 to 18 inches above the lip of the pit or riser crest elevation (basin dewatering), and filter material should extend 3 inches minimum above the anticipated standing water level.

**Effectiveness**

There is currently no information on the effectiveness of the sump pit.

**Limitations**

The sump pit must be properly maintained and pumped regularly to avoid clogging.

**Maintenance**

To maintain, sump pits must be removed and reconstructed when water can no longer be pumped out of the standpipe.

**Cost**

R. S. Means (2000) provides information appropriate for assessment of a wide range of dewatering scenarios (i.e., different sump sizes, dewatering durations, and discharge conditions). In general, installation of earthen sump pits are listed as costing approximately \$1.50 per cubic foot of sump volume. Piping to and away from the sump ranges from \$30 to \$60 per linear foot. Pump rentals and operation range between $150 and $500 per day of pumping, depending on the rate of dewatering. All costs include materials, labor, and equipment, with overhead and profit.

#### 5.1.5.4.4 Sediment Tank

**Description**

A sediment tank is a compartmented container through which sediment-laden water is pumped to trap and retain sediment prior to pumping the water to drainageways, adjoining properties, and rights-of-way below the sediment tank site.

**Applicability**

A sediment tank should be used on sites where excavations are deep and space is limited, such as urban construction, where direct discharge of sediment-laden water to streams and storm drainage systems should be avoided.

**Design and Installation Criteria**

The location of sediment tanks should facilitate easy cleanout and disposal of the trapped sediment to minimize interference with construction activities and pedestrian traffic. The tank size should be determined according to the storage volume of the sediment tank, with 1 cubic foot of storage for each gallon per minute of pump discharge capacity.

**Effectiveness**

There is currently no information on the effectiveness of sediment tanks.

**Limitations**

The sediment tank does not provide any natural infiltration; thus, the trapped sediment and storm water must be disposed of properly.

**Maintenance**

To facilitate maintenance of sediment tanks, they need to be located with easy access for regular pump out. The rate at which a tank is pumped depends on site specific considerations such as rainfall and sediment loads to the system. Regular inspections will help to determine pump out frequency and prevent overloading and failure of the system.

**Cost**

There is currently no information on the cost of sediment tanks.

#### 5.1.5.4.5 Stabilized Construction Entrance

**Description**

The purpose of stabilizing entrances to a construction site is to minimize the amount of sediment leaving the area as mud attached to tires. Installing a pad of gravel over filter cloth where construction traffic leaves a site can help stabilize a construction entrance. As a vehicle drives over the gravel pad, mud and other sediments are removed from the vehicle's wheels (sometimes by washing) and offsite transport of sediment is reduced. The gravel pad also reduces erosion and rutting on the soil beneath the stabilization structure. The fabric reduces the amount of rutting caused by vehicle tires by spreading the vehicle's weight over a larger soil area than just the tire width. The filter fabric also separates the gravel from the soil below, preventing the gravel from being ground into the soil.

**Applicability**

Stabilized construction entrances typically are installed at locations where construction traffic leaves or enters an existing paved road. However, the applicability of site entrance stabilization should be extended to any roadway or entrance where vehicles will access or leave the site.

From a public relations point of view, stabilizing construction site entrances can be a worthwhile exercise. If the site entrance is the most publicly noticeable part of a construction site, stabilized entrances can improve the appearance to passersby and improve public perception of the construction project by reducing the amount of mud tracked onto adjacent streets.

**Design and Installation Considerations**

*Hydrologic Design*

Not applicable.

*Installation Criteria and Specifications*

All entrances to a site should be stabilized before construction begins and further disturbance of the site area occurs. The stabilized site entrances should be long enough and wide enough so that the largest construction vehicle that will enter the site will fit in the entrance with room to spare. If many vehicles are expected to use an entrance in any one day, the site entrance should be wide enough for the passage of two vehicles at the same time with room on either side of each vehicle. For optimum effectiveness, a rock construction entrance should be at least 50 feet long and at least 10 to 12 feet wide (USEPA, 1992).

If a site entrance leads to a paved road, the end of entrance should be "flared" (made wider as in the shape of a funnel) so that long vehicles do not go off the stabilized area when turning onto or off of the paved roadway.

If a construction site entrance crosses a stream, swale, roadside channel, or other depression, a bridge or culvert should be provided to prevent erosion from unprotected banks.

Stone and gravel used to stabilize the construction site entrance should be large enough so that nothing is carried off-site with vehicle traffic. In addition, sharp-edged stone should be avoided to reduce the possibility of puncturing vehicle tires. Stone or gravel should be installed at a depth of at least 6 inches for the entire length and width of the stabilized construction entrance.

**Effectiveness**

Stabilizing construction entrances to prevent sediment transport off-site is effective only if all entrances to the site are stabilized and maintained. Also, stabilization of construction site entrances may not be very effective unless a wash rack is installed and routinely used (Corish, 1995), although this can be problematic for sites with multiple entrances that have high vehicle traffic.

**Limitations**

Although stabilizing a construction entrance is a good way to help reduce the amount of sediment leaving a site, some sediment may still be deposited from vehicle tires onto paved surfaces. To further reduce the chance that these sediments will pollute storm water runoff, sweeping of the paved area adjacent to the stabilized entrance is recommended.

For sites using wash stations, a reliable water source to wash vehicles before leaving the site might not be initially available. In this case, water may have to be trucked to the site at an additional cost. Discharge from the wash station should be directed to an appropriate sediment control structure.

**Maintenance**

Stabilization of site entrances should be maintained until the remainder of the construction site has been fully stabilized. Stone and gravel might need to be periodically added to each stabilized construction site entrance to maintain its effectiveness. Soil that is tracked offsite should be swept up immediately and disposed of properly.

For sites with wash racks at each site entrance, sediment traps will have to be constructed and maintained for the life of the project. Maintenance will entail the periodic removal of sediment from the traps to ensure their continued effectiveness.

**Cost**

Without a wash rack, construction site entrance stabilization costs range from $1,000 to $4,000. On average, the initial construction cost is approximately $2,000 per entrance. When maintenance costs are included, the average total annual cost for a 2-year period is approximately $1,500. If a wash rack is included in the construction site entrance stabilization, the initial construction costs range from $1,000 to $5,000, with an average initial cost of $3,000 per entrance. Total annual cost, including maintenance for an estimated 2-year life span, is approximately $2,200 per year (USEPA, 1993).

#### 5.1.5.4.6 Land Grading

**Description**

Land grading involves reshaping the ground surface to planned grades as determined by an engineering survey, evaluation, and layout. Land grading provides more suitable topography for buildings, facilities, and other land uses and helps to control surface runoff, soil erosion, and sedimentation both during and after construction.

**Applicability**

Land grading is applicable to sites with steep topography or easily erodible soils because it stabilizes slopes and decreases runoff velocity. Grading activities should maintain existing drainage patterns as much as possible.

**Design and Installation Criteria**

Before grading activities begin, decisions should be made regarding the steepness of cut-and-fill slopes and how the slopes will be protected from runoff, stabilized, and maintained. A grading plan that establishes which areas of the site will be graded, how drainage patterns will be directed, and how runoff velocities will affect receiving waters should be prepared. The grading plan also includes information regarding when earthwork will start and stop, establishes the degree and length of finished slopes, and dictates where and how excess material will be disposed of (or where borrow materials will be obtained if needed). Berms, diversions, and other storm water practices that require excavation and filling should also be incorporated into the grading plan.

One low-impact development technique that can be incorporated into a grading plan is site fingerprinting. This involves clearing and grading only those areas necessary for building activities and equipment traffic. Adhering to strict limits of clearing and grading helps to maintain undisturbed temporary or permanent buffer zones in the grading operation and provides a low-cost sediment control measure that will help reduce runoff and off-site sedimentation. The lowest elevation of the site should remain undisturbed to provide a protected storm water outlet before storm drains or other construction outlets are installed.

**Effectiveness**

Land grading is an effective means of reducing steep slopes and stabilizing highly erodible soils when implemented with storm water management and erosion and sediment control practices in mind. Land grading is not effective when drainage patterns are altered or when vegetated areas on the perimeter of the site are destroyed.

**Limitations**

Construction sites are routinely graded to prepare a site for buildings and other structures. Improper grading practices that disrupt natural storm water patterns might lead to poor drainage, high runoff velocities, and increased peak flows during storm events. Clearing and grading of the entire site without vegetated buffers promotes off-site transport of sediments and other pollutants. Grading plans should be designed with erosion and sediment control and storm water management goals in mind; grading crews should be carefully supervised to ensure that the plan is implemented as intended.

**Maintenance**

All graded areas and supporting erosion and sediment control practices should be periodically checked, especially after heavy rainfalls. All sediment should be promptly removed from diversions or other storm water conveyances. If washouts or breaks occur, they should be repaired immediately. Prompt maintenance of small-scale eroded areas is essential to prevent these areas from becoming significant gullies.

**Cost**

Land grading is practiced at virtually all construction sites—additional site planning to incorporate storm water and erosion and sediment controls in grading plans can require several hours of planning by a certified engineer or landscape architect. Extra time might be required to excavate diversions and construct berms, and fill materials might be needed to build up low-lying areas or fill depressions.

Where grading is performed to manage on-site storm water, R. S. Means (2000) suggests the cost of fine grading, soil treatment, and grassing to be approximately $2 per square yard of earth surface area. Shallow excavation/trenching (1 to 4 feet deep) with a backhoe in areas not requiring dewatering can be performed for $4 to $5 per cubic yard of removed material. Larger scale grading requires a site-specific assessment of an alternative grading apparatus and a detailed fill/excavation material balance to retain as much soil on site as possible.

### 5.1.5.4.7 Temporary Access Waterway Crossing

**Description**

A temporary stream crossing is a structure erected to provide a safe and stable way for construction vehicle traffic to cross a running watercourse. The primary purpose of such a structure is to provide streambank stabilization, to reduce the risk of damaging the streambed or channel, and to reduce the risk of sediment loading from construction traffic. A temporary stream crossing may be a bridge, culvert, or ford.

## Applicability

Temporary stream crossings are applicable wherever heavy construction equipment must be moved from one side of a stream channel to the other or where lighter construction vehicles will cross the stream a number of times during the construction period. In either case, an appropriate method for ensuring the stability of the streambanks and preventing large-scale erosion is necessary.

A bridge or culvert is the best choice for most temporary stream crossings. If properly designed, each can support heavy loads, and materials used to construct most bridges and culverts can be salvaged after they are removed. Fords are appropriate in steep areas subject to flash flooding, where normal flow is shallow or intermittent across a wide channel. Fords should be used only where stream crossings are expected to be infrequent.

## Design and Installation Criteria

Because of the potential for stream degradation, flooding, and safety hazards, stream crossings should be avoided on a construction site whenever possible. Consideration should be given to alternative site access routes before arrangements are made to erect a temporary stream crossing. If it is determined that a stream crossing is necessary, an area where the potential for erosion is low should be selected. The stream crossing structure should be installed during a dry period if possible to reduce sediment transport into the stream.

If needed, over-stream bridges are generally the preferred temporary stream crossing structure. The expected load and frequency of the stream crossing, however, will govern the selection of a bridge as the correct choice for a temporary stream crossing. These types of temporary bridges usually cause minimal disturbance to a stream's banks and cause the least obstruction to stream flow and fish migration. They should be constructed only under the supervision and approval of a qualified engineer.

As general guidelines for constructing temporary bridges, clearing and excavation of the stream shores and bed should be kept to a minimum. Sufficient clearance should be provided for floating objects to pass under the bridge. Abutments should be parallel to the stream and be placed on stable banks. If the stream is less than 8 feet wide at the point where a crossing is needed, no additional in-stream supports should be used. If the crossing is to extend across a channel wider than 8 feet (as measured from the top of one bank to the other), the bridge should be designed with one in-water support for each 8 feet of stream width.

A temporary bridge should be anchored by steel cable or chain on one side only to a stable structure on shore. Examples of anchoring structures include trees with a large diameter, large boulders, and steel anchors. By anchoring the bridge on one side only, there is a decreased risk of causing a downstream blockage or flow diversion if a bridge is washed out.

When constructing a culvert, filter cloth should be used to cover the streambed and streambanks to reduce settlement and improve the stability of the culvert structure. The filter cloth should extend a minimum of 6 inches and a maximum of 1 foot beyond the end of the culvert and bedding material. The culvert piping should not exceed 40 feet in length and should be of sufficient diameter to allow for complete passage of flow during peak flow periods. The culvert pipes should be covered with a minimum of 1 foot of aggregate. If multiple culverts are used, at least 1 foot of aggregate should separate the pipes.

Fords should be constructed of stabilizing material such as large rocks.

**Effectiveness**

Both temporary bridges and culverts provide an adequate path for construction traffic crossing a stream or watercourse.

**Limitations**

Bridges can be considered the greatest safety hazard of all temporary stream crossing structures if not properly designed and constructed. Bridges might also prove to be more costly in terms of repair costs and lost construction time if they wash out or collapse (Smolen et al., 1988).

The construction and removal of culverts are usually very disturbing to the surrounding area, and erosion and downstream movement of sediments are often great. Culverts can also create obstructions to flow in a stream and inhibit fish migration. Depending on their size, culverts can be blocked by large debris and are therefore vulnerable to frequent blockage and washout.

If given a choice between building a bridge or a culvert as a temporary stream crossing, a bridge is preferred because of the relative minimal disturbance to streambanks and the opportunity for unimpeded flow through the channel. The approaches to fords often have high erosion potential. In addition, excavation of the streambed and approach to lay riprap or other stabilization material causes major stream disturbance. Mud and other debris are transported directly into the stream unless the crossing is used only during periods of low flow.

**Maintenance**

Temporary stream crossings should be inspected at least once a week and after all significant rainfall events. If any structural damage is reported to a bridge or culvert, construction traffic should be excluded until appropriate repairs are made. Streambank erosion should be repaired immediately.

Fords should be inspected closely after major storm events to ensure that stabilization materials remain in place. If the material has moved downstream during periods of peak flow, the lost material should be replaced immediately.

**Cost**

In general, temporary bridges are more expensive to design and construct than culverts. Bridges are also associated with higher maintenance and repair costs should they fail. Temporary bridging costs vary as a function of the width of the bridge span and the amount of time the bridge is installed. If the bridging is permanent, a mean cost of $50 per square foot for an 8-foot wide steel arch bridge (no foundation costs included) can be used for conceptual cost estimation (R. S. Means, 2000). If rental bridging is employed, then rates are probably on the order of 20 to 50 percent of the bridge (permanent) cost, but will vary based on the rental duration and mobilization distance.

#### 5.1.5.4.8 Dust Control

**General Description**

Dust control measures are practices that help reduce ground surface and air movement of dust from disturbed soil surfaces. Construction sites are good candidates for dust control measures because land disturbance from clearing and excavation generates a large amount of soil disturbance and open space for wind to pick up dust particles. To illustrate this point, research at construction sites has established an average dust emission rate of 1.2 tons/acre/month for active construction (WA Dept. of Ecology, 1992). These airborne particles pose a dual threat to the environment and human health. First, dust can be carried off-site, thereby increasing soil loss from the construction area and increasing the likelihood of sedimentation and water pollution. Second, blowing dust particles can contribute to respiratory health problems and create an inhospitable work environment.

**Applicability**

Dust control measures are applicable to any construction site where dust is created and there is the potential for air and water pollution from dust traveling across the landscape or through the air. Dust control measures are particularly important in arid or semiarid regions where soil can become extremely dry and vulnerable to transport by high winds.

Also, dust control measures should be implemented on all construction sites where there will be major soil disturbances or heavy construction activity, such as clearing, excavation, demolition, or excessive vehicle traffic. Earthmoving activities are the major source of dust from construction sites, but traffic and general disturbances can also be major contributors (WA Dept. of Ecology, 1992).

The specific dust control measures implemented at a site will depend on the topography, land cover, soil characteristics and amount of rainfall at the site.

## Design and Installation Criteria

When designing a dust control plan for a site, the amount of soil exposed will dictate the quantity of dust generation and transport. Therefore, construction sequencing and disturbing small areas at one time can greatly reduce problematic dust from a site. If land must be disturbed, additional temporary stabilization measures should be considered prior to disturbance.

A number of methods can be used to control dust from a site. The following is a brief list of control measures and their design criteria. Not all control measures will be applicable to a given site. The owner, operator, and contractors responsible for dust control should determine which practices accommodate their needs based on specific site and weather conditions.

*Sprinkling/Irrigation*: Sprinkling the ground surface with water until it is moist is an effective dust control method for haul roads and other traffic routes (Smolen et al., 1988). This practice can be applied to almost any site.

*Vegetative Cover*: In areas not expected to handle vehicle traffic, vegetative stabilization of disturbed soil is often desirable. Vegetative cover provides protection to surface soils and slows wind velocity at the ground surface, thus reducing the potential for dust to become airborne.

*Mulch*: Mulching can be a quick and effective means of dust control for a recently disturbed area (Smolen et al., 1988).

*Wind Breaks*: Wind breaks are barriers (either natural or constructed) that reduce wind velocity and therefore reduce the possibility of carrying suspended particles. Wind breaks can be trees or shrubs left in place during site clearing or constructed barriers such as a wind fence, snow fence, tarp curtain, hay bale, crate wall, or sediment wall (USEPA, 1992).

*Tillage*: Deep tillage in large open areas brings soil clods to the surface where they rest on top of dust, preventing it from becoming airborne.

*Stone*: Stone can be an effective dust deterrent for construction roads and entrances.

*Spray-on Chemical Soil Treatments (palliatives)*: Examples of chemical adhesives include anionic asphalt emulsion, latex emulsion, resin-water emulsions, and calcium chloride. Chemical palliatives should be used only on mineral soils. When considering chemical application to suppress dust, consideration should be taken as to whether the chemical is biodegradable or water-soluble and what effect its application could have on the surrounding environment, including waterbodies and wildlife.

Table 5-23 shows application rates for some common spray-on adhesives as recommended by Smolen et al. (1988).

**Table 5-23. Application Rates for Spray-On Adhesives**

| Spray on Adhesive | Water Dilution | Type of Nozzle | Application |
|---|---|---|---|
| Anionic Asphalt Emulsion | 7:1 | Coarse spray | 1,200 |
| Latex Emulsion | 12.5:1 | Fine spray | 235 |
| Resin in Water | 4:1 | Fine spray | 300 |

Source: Smolen et al., 1988.

**Effectiveness**

*Sprinkling/irrigation*: Not available.

*Vegetative cover*: Not available.

*Mulch*: Can reduce wind erosion by 80 percent.

*Wind breaks/barriers*: For each foot of vertical height, an 8- to 10-foot deposition zone develops on the leeward side of the barrier. The barrier density and spacing will change its effectiveness at capturing windborne sediment.

*Tillage*: Roughening the soil can reduce soil losses by approximately 80 percent.

*Stone*: The sizes of the stone can affect the amount of erosion that will take place. In areas of high wind, small stones are not as effective as 20-cm stones.

*Spray-on chemical soil treatments (palliatives)*: Effectiveness of polymer stabilization methods ranges from 70 to 90 percent.

**Limitations**

In areas where evaporation rates are high, water application to exposed soils may require near constant attention. If water is applied in excess, runoff may result from the site and possibly create conditions where vehicles could track mud onto public roads.

Chemical applications should be used sparingly and only on mineral soils (not high organic content soils) because their misuse can create additional surface water pollution from runoff or could contaminate ground water if infiltrated. Chemical applications might also present a health risk if excessive amounts are used.

**Maintenance**

Because dust controls are dependent on specific site conditions, including the weather, inspection and maintenance are unique for each site. Generally, however, dust control measures involving application of either water or chemicals require more monitoring than structural or vegetative controls to remain effective. If structural controls are used, they should be inspected for deterioration on a regular basis to ensure they are still achieving their intended purpose.

**Cost**

Chemical dust control measures can vary widely in cost depending on specific needs of the site and level of dust control desired. One manufacturer of a chloride product estimated a cost of $1,089 per acre for application to road surfaces, but cautioned that cost estimates without a specific site evaluation can be inaccurate.

### 5.1.5.4.9 Storm Drain Inlet Protection

**Description**

Storm drain inlet protection measures are controls that help prevent soil and debris from on-site erosion from entering storm drain inlets. Typically, these measures are temporary controls that are implemented prior to large-scale disturbance of the surrounding site. These controls are advantageous because their implementation allows storm drains to be used during even the early stages of construction activities. The early use of storm drains during project development significantly reduces the occurrence of future erosion problems (Smolen et al., 1988).

Three temporary control measures to protect storm drain drop inlets are:

- Excavation around the perimeter of the drop inlet
- Fabric barriers around inlet entrances
- Block and gravel protection

Excavation around a storm drain inlet creates a settling pool to remove sediments. Weep holes protected by gravel are used to drain the shallow pool of water that accumulates around the inlet. A filter fabric barrier erected around an inlet can create an effective shield to sediment while allowing water to flow into the storm drain. This type of barrier can slow runoff velocity while catching soil and other debris at the drain inlet. Block and gravel inlet protection uses standard concrete blocks and gravel to form a barrier to sediments while permitting water runoff through select blocks that are laid sideways. In addition to these materials, limited temporary storm water drop inlet protection can also be achieved with the use of straw bales or sandbags to create barriers to sediment.

For permanent storm drain drop inlet protection after the surrounding area has been stabilized, sod can be installed as a barrier to slow storm water entry to storm drain inlets and capture sediments from erosion. This final inlet protection measure can be used as an aesthetically pleasing way to slow storm water velocity near drop inlet entrances and remove sediments and other pollutants from runoff.

A new technology that uses an insert trap into the inlet itself has been developed (Adams et al., 2000). This technique showed good results on initial tests, trapping more than 50 percent of the incoming sediment in flows typical of those into urban storm drains. This technique is being further developed with a pending patent application.

**Applicability**

All temporary controls should have a drainage area no greater than 1 acre of drainage area per inlet. It is also important for temporary controls to be constructed prior to disturbance of the surrounding landscape. Excavated drop inlet protection and block and gravel inlet protection are applicable to areas of high flow where overflow is anticipated into the storm drain. Fabric barriers are recommended for smaller, relatively flat drainage areas (slopes less than 5 percent leading to the storm drain).

Temporary drop inlet control measures are often used in combination with each other and with other storm water control techniques.

**Design and Installation Considerations**

*Hydrologic Design*

Hydrologic computations are not necessary with present technologies. A specified limitation of 1 drainage acre per inlet limits flow rates, dependent on local rainfall and runoff considerations.

*Installation Criteria and Specifications*

The following criteria should be followed until future research establishes better techniques:

- With the exception of sod drop inlet protection, these controls should be installed before any soil disturbance in the drainage area.

- Excavation around drop inlets should be dug a minimum of 1 foot deep (2 feet maximum) with a minimum excavated volume of 35 cubic yards per acre disturbed. Side slopes leading to the inlet should be no steeper than 2:1. The shape of the excavated area should be designed such that the dimensions fit the area from which storm water is anticipated to drain. For example, the longest side of an excavated area should be along the side of the inlet expected to drain the largest area.

- Fabric inlet protection is essentially a filter fence placed around the inlet. The fabric should not be used as a stand-alone sediment control measures. To increase inlet protection effectiveness, these practices should be used in combination with other measures, such as small impoundments or sediment traps (USEPA, 1992). Temporary storm drain inlet protection is not intended for use in drainage areas larger than 1 acre. Generally, storm water inlet protection measures are practical for relatively low sediment and low volume flows.

- Frequent maintenance of storm drain controls is necessary to prevent clogging. If sediment and other debris clog the water intake, drop intake control measures can actually cause erosion in unprotected areas.

**Maintenance**

All temporary control measures must be checked after each storm event. To maintain the sediment capacity of the shallow settling pools created from these techniques, accumulated sediment should be removed from the area around the drop inlet (i.e., from the excavated area, around the fabric barrier, or around the block structure) when the sediment storage is reduced by approximately 50 percent. Additional debris should be removed from the shallow pools on a periodic basis.

Weep holes in excavated areas around inlets can become clogged and prevent water from draining from the shallow pools that form. Should this happen, unclogging the water intake may be difficult and costly.

**Cost**

The cost of implementing storm drain drop inlet protection measures will vary depending on the control measure chosen. Generally, initial installation costs range from $50 to $150 per inlet, with an average cost of $100 (USEPA, 1993). Maintenance costs can be high (annually, up to 100 percent of the initial construction cost) because of frequent inspection and repair needs. The Southeastern Wisconsin Regional Planning Commission has estimated that the cost of installation of inlet protection devices ranges from $106 to $154 per inlet (SWRPC, 1991).

### 5.1.5.4.10 Polyacrylamide (PAM)

**General Description**

The term polyacrylamide (PAM) is a generic term that refers to a broad class of compounds. There are hundreds of specific PAM formulations, and all have unique properties that depend on polymer chain length and number and kinds of functional group substitutions along the chain. PAMs are classified according to their molecular weight and ionic charge and are available in solid, granular, liquid, or emulsion forms.

PAM’s effectiveness to prevent or reduce erosion is due to its affinity for soil particles, largely via coulombic and Van der Waals attraction. These surface attractions enhance particle cohesion, stabilizing soil structure against shear-induced detachment and transport in runoff. In a soil application, PAM aggregates soil particles, increasing pore space and infiltration capacity and resulting in reduced runoff. These larger particle aggregates are less susceptible to raindrop and scour erosion, thus reducing the potential to mobilize sediments.

**Applicability**

Because of ease in application, PAM is well suited as a short-term erosion prevention BMP, especially for areas with limited access or steep slopes that hinder personnel from applying other cover materials. PAM can be used to augment other cover practice BMPs, though it can be effective when applied alone. Thus, the ease of application, low maintenance, and relatively low cost associated with PAM make it a practical solution to soil stabilization during construction.

**Application Criteria**

PAM can be applied to soil through either a dry granular powder or a liquid spray form. Optimal application rates to prevent erosion on construction sites are generally less than 1 kg/ha (approximately 1 lb/ac) (Tobiason et al., 2000). However, the concentration required can vary for specific soil properties and construction phases. WDOT (2002) suggests a dosage of 60 mg/L for roadway erosion and sediment control. This is higher than the rate recommended by the University of Nebraska for an agricultural application (10 parts per million). To put this into context, one half pound of PAM in1,000 gallons of water results in a PAM concentration of 60 mg/L, which treats 1 acre of exposed soil according to WDOT recommendations.

**Effectiveness**

A study performed in Dane County, Wisconsin, analyzed 15 meter square plots for runoff and sediment yield on a construction site. The study concluded that when a solution of PAM-mix with mulch/seeding was applied to dry soil and compared with the control (no PAM-mix application to dry soil), an average reduction of 93 percent in sediment yield was found. The lowest performance (average reduction in sediment yield of 77 percent) occurred when PAM-mix in solution was applied to moist soil. The application of dry PAM-mix to dry soil reduced sediment by 83 percent and decreased runoff by 16 percent when compared to the control. The results show that regardless of the application method, PAM-mix was effective in reducing sediment yield in the test plots (Roa-Espinosa et al., 2000).

A second study performed in Washington analyzed the runoff from three different construction sites: an erosion control test facility, a highway construction site, and an airport runway. Table 5-24 summarizes the 225 samples analyzed by Tobiason et al. (2000).

**Table 5-24. Turbidity Reduction Values from PAM**

| | Volume, $m^3$ | Turbidity Reduction (%) |
|---|---:|---:|
| Maximum | 350 | 99.97 |
| Median | 285 | 97.6 |
| Minimum | 133 | 46 |

**Limitations**

Currently PAMs are most commonly produced as dry granules. They completely dissolve and remain dissolved if mixed properly. If added too quickly or if not stirred vigorously, the granules rapidly form nondissolvable gels on contact with water or collect in low turbulence areas as syrupy concentrations that dissolve slowly in an uncontrolled pattern over a period of hours or days (USDA, 1994). In addition, when spilled on hard surfaces, PAM solutions are extremely slippery and hazardous to foot and vehicle traffic. PAM dust is highly hygroscopic and, if inhaled, could impair breathing. Certain neutral and cationic PAMs at very high exposure levels produce irritation in humans and are somewhat toxic to certain aquatic organisms; therefore, PAM should be used in strict compliance with state and federal label requirements. Finally, although PAM is relatively inexpensive, there are considerable infrastructure needs and operating costs; thus, sophisticated onsite polymer treatment systems may not be appropriate for certain projects.

**Cost**

The cost of PAM ranges from $1.25 per pound to $5.00 per pound (Entry et al., 1999). The cost of PAM application depends on the system employed. PAM can be used in a centralized treatment system (e.g., at a sedimentation basin) to treat larger areas, or dispersed in granular or liquid form. In Tobiason et al. (2000), the startup costs for the batch treatment system amounted to $90,000. Monthly expenses averaged $18,000 for operations and maintenance and $13,000 for materials and equipment. The total costs for this phase totaled about $245,000, less than 1 percent of total construction costs. If dispersed through irrigation systems (for agriculture), the seasonal cost of PAM treatment is $9 to $15 per acre (Kay-Shoemake, et al., 2000), where a season probably requires between 5 and 10 applications.

For construction sites, it is more likely that PAM would be applied as an additive to the hydroseed mix and applied when final grade is established and cover vegetation is installed. There are numerous suppliers who provide PAM as a low-cost additive for hydroseeding, suggesting PAM application costs can be incorporated into that of hydroseeding ($540 to $700 per acre depending on which seed is applied). An additional cost would be incurred to sample site soils to customize the dosage and delivery mechanisms for individual sites. In addition, re-application of PAM in granular or liquid form to areas with rill development (poor vegetation cover) would require additional funds. Where re-application of granular PAM is used, R. S. Means (2000) suggests a cost of approximately $5 per 1,000 square feet for spreading soil admixtures by hand.

### 5.1.6 SUMMARY

The BMP information presented in sub-section 5.1 is summarized in Tables 5-25 through 5-28.

**Table 5-25. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.1)**

| BMP Type | Physical Impact Mitigation | | Other Impacts |
|---|---|---|---|
| | Receiving Water Quality | Downstream Impacts | |
| Planning/ Staging/ Scheduling | • Could be low cost.<br>• One data set shows 42% reduction in sediment yield due to planning/staging/scheduling.<br>• Requires additional advance planning and management.<br>• Impact could be evaluated with models as well as experimentally since several computer models are available. | • Could be low cost.<br>• Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |
| Vegetative Stabilization | • Could be low cost<br>• Can be very effective in some cases with advance planning.<br>• Can be important on streambanks.<br>• Limited applicability in the active construction area.<br>• Complements other practices.<br>• Practice is seasonally dependent in most of nation.<br>• Impact could be evaluated with models as well as experimentally since several computer models are available. | • Could be low cost.<br>• Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |
| Grass-Lined Channels | • Long history of use in channels draining disturbed areas.<br>• Well established procedures for design and extensive database on stable designs under widely varied conditions.<br>• Some procedures are available, with limited validation, to obtain a first estimate of sediment trapping by grass-lined channels.<br>• Limited database on trapping of sediment.<br>• Maintenance is critical for pollution prevention. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Database shows wide variations in effectiveness in trapping chemicals.<br>• Other impacts not evaluated. |

**Table 5-25. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.1)**

| BMP Type | Physical Impact Mitigation | | Other Impacts |
|---|---|---|---|
| | Receiving Water Quality | Downstream Impacts | |
| Seeding | • Low-cost method for establishing vegetation.<br>• Occurs near the end of active construction.<br>• Requires significant time for establishment.<br>• Needs a prepared seedbed.<br>• Good database with impacts on soil erosion.<br>• Should be supported by other BMPs. | • Should not be evaluated as stand-alone practice, but as part of a system.<br>• Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |
| Sodding | • High-cost method of establishing vegetation.<br>• Immediate stabilization.<br>• Requires significant management attention during establishment.<br>• Good database with impacts on soil erosion.<br>• Very effective way of controlling erosion.<br>• Works well for grass waterways and other significant problem areas.<br>• Should be supported by other BMPs. | • Should not be evaluated as stand-alone practice, but as part of a system.<br>• Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |
| Mulching | • Relatively low-cost method of providing cover.<br>• Can be highly effective in reducing soil loss when properly anchored.<br>• Good database with impacts on soil erosion.<br>• Variety of materials can be used.<br>• Installation is rapid.<br>• Not a stand-alone practice.<br>• Due to interference with construction operations, the times that it can be used during active construction are limited. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |

**Table 5-25. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.1)**

| BMP Type | Physical Impact Mitigation | | Other Impacts |
|---|---|---|---|
| | **Receiving Water Quality** | **Downstream Impacts** | |
| Erosion Control Matting /Geotextiles | • Cost is highly variable.<br>• Effectiveness in controlling sediment is variable depending on types of materials.<br>• Can provide immediate protection to exposed soils.<br>• Not a stand-alone practice.<br>• Due to interference with construction operations, the times that it can be used during active construction are limited.<br>• Disposal is a significant problem and may require landfilling.<br>• Can be used for channel linings as astand-alone practice or under riprap.<br>• Fair database on effectiveness in preventing erosion. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |
| Vegetative Buffer Strips | • Can be highly effective in trapping sediment.<br>• Effectiveness is well established and considerable data have been collected.<br>• Well-validated models are available to predict the impacts of constructed filter strips on sediment trapping.<br>• Models are included in watershed storm water and sediment models.<br>• Modifications needed for natural riparian zones.<br>• Require routine maintenance.<br>• May be most appropriate where sediment loads are relatively low. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |
| Topsoiling | • Important in vegetative establishment.<br>• No protection until cover is established.<br>• Not a stand-alone practice; must be supported by other BMPs.<br>• No known information to describe effectiveness<br>• Cost not currently available. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |

**Table 5-26. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.2)**

| BMP Type | Physical Impact Mitigation: Receiving Water Quality | Physical Impact Mitigation: Downstream Impacts | Other Impacts |
|---|---|---|---|
| Earth Dike | • Used to protect down slope areas.<br>• Should be stabilized prior to use.<br>• Requires maintenance after every major storm.<br>• Can be significant source of sediment if not properly constructed.<br>• Little data available on its effectiveness as a BMP.<br>• Can be relatively inexpensive, depending on design.<br>• Not a stand-alone procedure. | • No known information available. | • No known information available. |
| Temporary Swale | • Effectively a grass-lined drainage ditch with shallow side slopes.<br>• Can be applied in many areas, but use limited in arid areas.<br>• Contaminants that will harm vegetation, such as oils and greases, cannot be discharged to the system.<br>• Continuous water flow cannot be tolerated by the grass lining.<br>• Effectiveness depends on infiltration. Ground water pollution might occur in areas with a high water table.<br>• Export of bacteria might occur.<br>• Some studies show high removal efficiency for TSS, fair removal for nutrients, are variable removal for metals.<br>• No general relationships available to predict impacts under widely varied climates and conditions, hence the effectiveness cannot be predicted for a given situation beyond the limited database. | • No known information available. | • No known information available. |

**Table 5-26. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.2)**

| BMP Type | Physical Impact Mitigation: Receiving Water Quality | Physical Impact Mitigation: Downstream Impacts | Other Impacts |
|---|---|---|---|
| Temporary Storm Drain Diversion (Pipe) | • Reroutes existing drainage systems. Primary benefit is to separate drainage water originating from undisturbed and construction and reduce the volume of water to be treated.<br>• Can be combined with other structures, such as sediment traps, and used for sediment trapping.<br>• Require little maintenance.<br>• Requires outlet stabilization. Can be a significant source of sediment without outlet stabilization.<br>• Can be costly, depending on size, installation, and removal. | • No known information available. | • No known information available. |
| Pipe Slope Drain | • Routes runoff from concentrated flow to stabilized areas.<br>• Can be very effective in eliminating gully erosion problems, if properly installed and maintained.<br>• Can be constructed from low-cost corrugated PVC, but must be anchored or buried along slope.<br>• Needs to be checked frequently for sedimentation and other maintenance problems. | • No known information available. | • No known information available. |

**Table 5-26. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.2)**

| BMP Type | Physical Impact Mitigation: Receiving Water Quality | Physical Impact Mitigation: Downstream Impacts | Other Impacts |
|---|---|---|---|
| Stone Check Dams | • Reduces velocity of flow and prevents erosion.<br>• Stabilizes channel slope on steep sections by stairstepping.<br>• Can trap small percentages of sediment behind dam.<br>• Used for short periods of time where channel lining is impractical.<br>• Limited lab studies show high effectiveness, but very limited field studies show low trapping efficiency. Must be installed such that overtopping occurs over the rock fill and not around the perimeter.<br>• Should not be used in continuously flowing streams.<br>• Relatively expensive, if properly installed.<br>• Procedures for predicting impact of properly installed stone check dams are available and incorporated into watershed computer models. | • No known information available. | • No known information available. |
| Lined Waterways | • Designed for stability and capacity.<br>• Local rainfall-runoff conditions and linings will influence channel dimensions.<br>• Require some maintenance during vegetative establishment.<br>• Not designed as sediment removal device, but to prevent channel erosion. | • No known information available. | • No known information available. |

**Table 5-27. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.3)**

| BMP Type | Physical Impact Mitigation | | |
|---|---|---|---|
| | Receiving Water Quality | Downstream Impacts | Other Impacts |
| Silt Fence | • Most widely recognized sediment control BMP.<br>• Frequently poorly installed with few design considerations.<br>• Maintenance is frequently poor, resulting in frequent failure. Frequent maintenance is required for proper operation.<br>• Laboratory studies show fair to good sediment trapping by filter fence, but limited field studies do not show the same results.<br>• Evaluations of installations show that failure is frequent and results from undercutting of the fabric and subsequent gully erosion.<br>• Should not be installed where rocks and other hard surfaces prevent anchoring.<br>• No validated procedures are available to predict the effectiveness of the filter fence in trapping sediment, primarily because of the lack of validated relationships for predicting flow through the filter fence.<br>• Procedures for evaluating the anchoring requirements and support post requirements have not adequately accounted for variable soil strength conditions, resulting in frequent failure of the fence under loading. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |
| Super Silt fence | • Modification of standard silt-fence to improve it structurally.<br>• No validation information is available.<br>• Recommended to be used where destruction of the silt fence will destroy critical areas.<br>• More expensive than standard silt fence. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |

**Table 5-27. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.3)**

| BMP Type | Physical Impact Mitigation | | Other Impacts |
|---|---|---|---|
| | **Receiving Water Quality** | **Downstream Impacts** | |
| Straw Bale Dike | • Works by impounding water.<br>• Primary trapping mechanism is by settling behind straw bale dike.<br>• Information on performance is very limited with much variation in the limited data.<br>• Should not be used in waterways or as a perimeter control due to biodegradation.<br>• Idealized models of performance are available for systems that are properly installed. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No good cause-effect relationships available.<br>• Other impacts not evaluated. |
| Sediment Traps | • Formed by excavation and/or embankment.<br>• Can simplify storm water control by trapping sediment at specific spots.<br>• Can be installed quickly and serve as a short-term solution to sediment trapping in small areas.<br>• May require cleanout.<br>• Detailed models as well as simplified design aids are available to predict performance in trapping sediment.<br>• Data on performance are available from both laboratory studies and field studies.<br>• Will likely control only the settleable solids unless enhanced settling with chemical flocculation is performed. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • Data for trapping nutrients are available, but show wide variation.<br>• General models of nutrient trapping are not available.<br>• Other impacts not evaluated. |

**Table 5-27. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.3)**

| BMP Type | Physical Impact Mitigation | | Other Impacts |
|---|---|---|---|
| | Receiving Water Quality | Downstream Impacts | |
| Sediment Basins | • Normally formed by construction of a dam.<br>• Storm water detention basin may serve as sediment basin during construction.<br>• Can be used for any size watershed.<br>• May require cleanout.<br>• Data on performance are available both from laboratory studies and field studies.<br>• Will likely control only the settleable solids unless enhanced settling is developed with chemical flocculation.<br>• Most reliable and stable structure for obtaining high sediment trapping efficiency under widely varying conditions.<br>• Must consider dam safety issues since dam failure is a reasonable possibility.<br>• Structures are relatively large and can be expensive. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • Data for trapping nutrients are available, but show wide variation.<br>• General models of nutrient trapping are not available.<br>• Other impacts not evaluated. |

**Table 5-28. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.4)**

| BMP Type | Physical Impact Mitigation: Receiving Water Quality | Physical Impact Mitigation: Downstream Impacts | Other Impacts |
|---|---|---|---|
| Stone Outlet Structures | • Porous outlet structure constructed of dumped rock, used as the outlet for earth dikes.<br>• Requires a stabilized outlet channel until the flow reaches a stable channel.<br>• Effectiveness data are limited to visual observations of field installations where failure occurred due to poor installation.<br>• Models are available to predict the performance of stone outlets, but field data have not been collected to evaluate the accuracy of the model. | • No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • General models of nutrient trapping are not available.<br>• Other impacts not evaluated. |
| Rock Outlet Protection | • Used to reduce velocity of flow in receiving channel and prevent scouring.<br>• Very effective when properly installed.<br>• Design procedures are well established.<br>• Maintenance is low, if properly installed.<br>• Should be inspected after high flows.<br>• No data on impact. | • No data available. | • No data available. |
| Sump Pit | • Used to dewater during excavation.<br>• Effectiveness not evaluated.<br>• Potential exists to theoretically evaluate the BMP's effectiveness in trapping sediment.<br>• Could be used at times other than storm flow, such as for removal of ground water flow. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No data available. |

**Table 5-28. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.4)**

| BMP Type | Physical Impact Mitigation: Receiving Water Quality | Physical Impact Mitigation: Downstream Impacts | Other Impacts |
|---|---|---|---|
| Storm Drain Inlet Protection | • Used to trap sediment that would otherwise flow into storm drain inlet.<br>• Should be installed prior to land disturbance.<br>• Effectiveness in removing sediment has not been evaluated, but is thought to be low during construction.<br>• Potential exists to use computer models to evaluate effectiveness.<br>• Cost can be high for maintenance requirements.<br>• Should not be used as stand-alone sediment control. | • Database is poor.<br>• No validated urban runoff models available for theoretical analysis of downstream impacts.<br>• Some potential exists to modify existing models to analyze downstream impacts on geomorphology. | • No data available. |
| Sediment Tank | • Portable sediment trap.<br>• Flows are pumped in and out of the tank.<br>• Used where spaced is limited.<br>• No effectiveness data are available.<br>• Expected to be relatively expensive. | • No data available. | • No data available. |
| Stabilized Construction Entrance | • Used to minimize mud and sediment attached to tires.<br>• Consists of an area that is covered with rocks over which all vehicles must drive.<br>• Can be combined with a wash station.<br>• Effective only if all entrances are maintained.<br>• Relatively expensive.<br>• Will not remove highly cohesive clays. | • No data available. | • No data available. |
| Land Grading | • Stabilizes slopes and decreases runoff velocity.<br>• Can be incorporated into low-impact development plans.<br>• Not effective when drainage patterns are altered.<br>• Not effective when vegetative areas on perimeter are destroyed.<br>• Practiced at virtually all construction sites.<br>• No data available on BMP effectiveness. | • No data available. | • No data available. |

**Table 5-28. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.4)**

| BMP Type | Physical Impact Mitigation: Receiving Water Quality | Physical Impact Mitigation: Downstream Impacts | Other Impacts |
|---|---|---|---|
| Temp Access Waterways Crossing | • Reduces risk to damaging streambed from construction equipment.<br>• Can be a bridge, culvert, or ford.<br>• Bridges and culverts preferred, but more expensive.<br>• Data on effectiveness in reducing sediment are not available. | • No data available. | • No data available. |
| Dust Control | • Important in arid and semi-arid regions.<br>• Applicable to any construction site.<br>• Construction sequencing and limiting exposure area can reduce problems.<br>• Spray-on adhesives are recommended.<br>• Water application may require near-constant attention.<br>• Excess water may cause runoff or tracking of mud.<br>• Very limited effectiveness information available.<br>• Costs can vary widely, depending on local conditions. | • No data available. | • No data available. |

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